Practice, policy and professional roles:

unintended consequences and performance gaps

in UK domestic solid wall insulation retrofit projects

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The idea of self-denial for the sake of posterity, of practising present economy for the sake of debtors yet unborn, of planting forests that our descendants may live under their shade, or of raising cities for future nations to inhabit, never, I suppose, efficiently takes place among publicly recognised motives of exertion. Yet these are not the less our duties; nor is our part fitly sustained upon the earth, unless the range of our intended and deliberate usefulness include, not only the companions but the successors of our pilgrimage.

\- John Ruskin

Summary

Space heating in domestic buildings accounts for roughly one-fifth of UK greenhouse gas emissions. There are roughly 11 million homes in the UK potentially suitable for solid wall insulation (including hard-to-treat cavity constructions). Remarkably, approximately 97 per cent of homes built with solid walls have no wall insulation. Retrofitting these homes with insulation offers the potential to significantly reduce national greenhouse gas emissions while reducing expenditure on fuel, improving thermal comfort and realising numerous important associated benefits. This research began at the onset of an upsurge in national rates of solid wall insulation retrofit in 2011-2012. At that time, anecdotal reports pointed toward a legacy of poor practices and continued problems in the retrofit industry.

A literature review outlines knowledge about the risks of performance gaps and unintended consequences. Participant and non-participant observation, site inspection and qualitative study are employed in area-based retrofit projects and across a variety of related settings. Analysis interprets observations against a range of existing theory and develops new theoretical insights.

Findings convey an understanding of a subset of the landscape in which retrofitting occurs and identify a number of challenges to improving practice. The perspectives of installers, managers, trainers and a range of professionals are reported. The research suggests that unintended consequences are likely to result from many observed practices and cautions that if these practices are typical of wider realities and remain unchanged, then serious problems may be propagated across many projects if growth in retrofitting continues as expected. Findings identify factors of quality in retrofits ranging from construction management, training, certification, technology, identity and motivation, and government policy instruments.

Emerging from the research is a definition of ‘quality’ against which retrofits can be evaluated. This forms the basis for evaluation of a number of proposed interventions and routes to improved practice.

Acknowledgements

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List of acronyms and abbreviations

ACoPs = Approved Code of Practices
ANT = Actor Network Theory
BBA = British Board of Agrément
BBRI = Belgium Buildling Research Institute
BISF = British Iron and Steel Federation
BRE = Building Research Establishment
BSEI = Building Sector Education Institute (Luxembourg)
BWIC = Builder's Work in Connection
CAQDAS = Computer-assisted qualitative data analysis software
CERT = Carbon Emissions Reduction Target
CESP = Community Energy Savings Programme
CFD = Computational fluid dynamics
CITB = Construction Industry Training Board
CLG = Department for Communities and Local Government
CoP = Community of Practice
DCLG = Department for Communities and Local Government
DECC = Department of Energy and Climate Change
Dilaps = Dilapidation surveys
DPC = Damp proof course
ECO = Energy Company Obligation
EPBD = Energy Performance of Buildings Directive
EPC = Energy Performance Certificate
EU = European Union
EWI = External Wall Insulation
GDA = Green Deal Assessor
GHG = greenhouse gas emissions
GSL = Government Soft Landings
GT = Grounded Theory
$GtCO_2e$ = Gigatonnes carbon dioxide equivalent
GWP = global warming potential
HFC = hydrofluorocarbon
HSE = Health and Safety Executive
IAQ = Indoor air quality
IWI = Internal Wall Insulation
LCA = life cycle assessment
LPP = Legitimate peripheral participation
LZC = Low zero carbon
m^2K/W = metre squared times degree kelvin per watt
MMC = modern methods of construction
NGB = Non-Governmental Body
NPV = Net present value
NVQ = National Vocational Qualification
NVQ2 = National Vocational Qualification Level 2
OSAT = On-site Skills Assessment and Training
PDR = Performance development review
PPE = Personal protective equipment
QA = Quality assurance
QC = Quality Control
QCF = Qualifications and Credit Framework
QS = Quantity surveyor
RAMS = Risk Assessment Method Statement

RdSAP = Reduced Data Standard Assessment Procedure
RMI = Repair, Maintenance and Improvement
SAP = Standard Assessment Procedure
SCM = Supply chain management
SME = Small-Medium Enterprise
STS = Science and Technology Studies
SVP = Soil and Vent Pipe
SWI = Solid Wall Insulation
SWIGA = Solid Wall Insulation Guarantee Association
TLO = Tenant Liaison Officer
TQM = Total Quality Management
UHI = Urban Heat Island Effect
VCL = vapour control layer
W/m^2K = Watts per metre squared times degree kelvin
WBCSD = World Business Council for Sustainable Development
WCC = Wallonia Construction Confederation
WUFI® = **W**ärme **U**nd **F**euchte **I**nstationär

1 Introduction

1.1 Aims

Solid wall insulation' (SWI) refers to insulation applied to the internal or external face of an exterior solid or 'hard-to-treat' cavity wall.[1]

This research began in 2011 when rapid growth in SWI retrofitting in the UK was beginning to be driven by several government policy instruments. Anecdotal reports widely indicated that historically, practices in the retrofit installation industry had been inconsistent with best practices understood in the research community. Researchers understood that poor installation or specification of SWI retrofit presented significant risks of unintended consequences, including damage to building fabric, loss of energy performance or service life, and impacts on human health and comfort.

Throughout the previous century, SWI remained a niche endeavour in the UK. In the years leading up to this research the total number of installations had remained relatively insignificant, but had gradually begun to rise. As it became clear that government policy would begin to drive SWI installations, a better understanding of practices in the industry became increasingly important.

This research aims to improve the understanding of practices in the SWI industry and to identify challenges it faces in delivering consistent build-quality and eliminating unintended consequences from retrofits. It examines practices within a small subset of the industry and studies the landscape within which retrofits occur.

It adopts a 'bottom-up', inductive and interrogative approach to develop understandings of and explanations for installation and specification practices. It is not undertaken to test pre-existing theory; rather, it addresses an understudied topic by compiling observations and developing new theoretical explanations.

[1] Definitions of hard-to-treat cavities vary, but in general the term refers to cavities that are more difficult or considerably more expensive to insulate than standard cavity constructions. Common factors include narrow cavities, metal frame constructions, concrete wall construction, areas of high rain or wind exposure, or building heights over three to four storeys (the UK Government's Energy Company Obligation programme, which stimulated much of the work observed in this research, deems dwellings over three storeys as hard-to-treat, but disregards some factors which assessors may not be able to identify readily such as high rain or wind exposure).

1.2 Thesis rationale

There are many reasons why insulating UK solid wall housing should be undertaken. Among the most obvious of which is the potential to reduce energy demand related to heating -- and to a lesser extent, cooling -- homes. Improving fabric efficiency serves not just to mitigate the vast contributions from housing to national GHG emissions, but also to reduce demand for fuel and natural resources. The exigency of mitigating the causes of climate change while also improving resilience to its impacts is clear. Obvious, too, is that a significant proportion of the nation's population faces health and comfort problems linked to uninsulated housing, while many millions are under economic duress due in part to inadequate energy efficiency (Wilkinson et al. 2009; Thomson et al. 2013; Ganten et al. 2010).

The UK has a great number of houses built before the advent of thermal standards or modern levels of energy performance and is generally considered to have the least energy efficient housing stock in Europe. Given current trajectories, the majority of this housing will remain in use at least for several more decades; general predictions suggest over 80 per cent of the housing we will have in 2050 has already been built. There is a clear need to refurbish a substantial proportion of the nation's housing.

National and international energy policy, coupled with national housing standards and fuel expenditure policies make up the dominant drivers of SWI retrofitting in the UK today. A review of these policies is provided in the following chapter (Section 2.3).

Out of a national stock of 27 million homes, roughly 97 per cent of the 7.8 million homes built of solid wall construction have not been insulated. Most of the potential for insulating cavity walls has already been achieved; of the 5.3 million homes that have not been insulated, 4.8 million are hard-to-treat cavity construction. Taken together -- not discounting the relatively small number of the homes which would be unsuitable for SWI (e.g. some heritage properties, homes with unsuitable construction or in extreme environmental exposures) -- this leaves roughly 11 million homes with the potential for SWI retrofit. DECC 2014a)

The best estimates of the total number of SWI installations in the UK are provided by DECC, which indicates that installations have only recently exceeded 200,000 (DECC 2012c; DECC 2013). Growth in installations, however, expanded rapidly immediately before and during this research. Government statistics indicate that the total number of installations roughly doubled between mid-2011 and mid-2013, and roughly tripled between 2009 and mid-2013 -- growing at approximately 30 per cent to 45 per cent per annum.

Although concern that a legacy of poor practice in the SWI industry has existed for many years is shared by many experts, this has remained unsubstantiated by research. A considerable body of evidence about energy performance and construction in general indicates that performance gaps are widespread (Zero Carbon Hub 2014).

The implications of poor specification and installation of SWI are severe. Risks include interstitial and surface condensation, impacts on indoor air quality (IAQ), moisture ingress, vapour build-up, and excessive summertime internal air temperatures. These carry implications not just for energy performance gaps, but also the integrity of existing building fabric, and hazards to occupant health such as cold-related illnesses and poor IAQ (Wilkinson et al. 2009; Ganten et al. 2010). Mitigation of the risks requires that installers have appropriate levels of skill and understanding, and work within a system of effective training, certification and construction management.

Installation work is widely carried out by SMEs, which in turn often subcontract to small and micro enterprises in what are essentially design-build contracts.[2] In the context of a history of limited take-up (and low rates of innovation), anecdotal reporting from many observers indicates that the SWI installation industry today is a highly fragmented group of actors with generally immature construction management practices. No evidence contradicting this characterisation has been found in research.

Although retrofitting existing homes is increasing, and it is critical to achieving national energy and carbon targets, research of energy use in the built environment has to date largely overlooked the implications of installation practice in retrofits. As Killip argues in his thesis (2011, p.2), despite considerable research on energy demand and supply scenarios, energy policy, occupant behaviour and cultural influences on energy demand, there is a lack of research focusing on the “agents of practical change in [energy refurbishment] technology deployment” and the impact they have on energy efficiency.

Extensive academic literature outlines the risks of unintended consequences in SWI. There has already been substantive study analysing hygrothermal risk, examining specification and material design and outlining ‘how best’ to insulate solid walls. Despite some remaining deficiencies, the research in this area is approaching maturity.

[2] The requirement for ‘design’ in SWI is limited to 'buildability workarounds' to manufacturers’ standardised installation specifications.

Literature is almost entirely devoid, however, of assessment of SWI practice, risks in as-built retrofits, and strategies for improving practices. Considered study of SWI installers and the impact they have on performance gaps has not yet been published.

Two critical questions have not yet been resolved: how common is inappropriate specification and 'poor' installer practice, and what are the root causes of their variability. These are distinct questions and call for different research strategies. It is not possible to answer either definitively within the confines of a doctoral research project. Ascertaining the actual frequency of poor practice would be best approached in a research project with resources more extensive than have been available here. Likewise, developing a comprehensive delineation of root causes in the variability in practices would require maturity in research impossible to achieve in this study.

It is against the challenge of reducing energy demand in line with government targets and policies that this research has been developed to examine the issue of unintended consequences and performance gaps. This thesis does not attempt to offer definitive explanations or test any existing theory. Instead, it approaches a considerable research gap with the simple ambition of contributing one small stone to the pile -- one insight upon which future research might build and practitioners and those with a role to play in retrofitting might reflect.

1.3 Boundaries

This thesis examines the challenges involved in delivering SWI installations. Insulating solid wall buildings is a complex undertaking involving mechanical processes, considerations of climate and material properties, detailing solutions and skill. A wide range of factors are at play in SWI. Many contextual factors are discussed in this research and its analysis of challenges to – and drivers of – SWI practice. Due to the practical constraints of this project, however, some limiting of scope has been necessary.

This research began in September 2011 and was completed in September 2015. The field research was conducted from late 2012 through the end of 2013. This was followed by a one-year period of analysis and writing, and several months spent completing this thesis. Literature review was concentrated between September 2011 and July 2014 and ceased in August 2015 (several texts published after this date are also included).

This work generally does not draw on comparisons to non-UK contexts, new-build construction, or non-domestic projects. The decision to limit investigation to the UK was based foremost on practical constraints in the project. Moreover, differences in climate outside the UK, in the character of non-UK construction industries and vocational training, and in building stock and technology, drove this decision. Although the use of SWI in new-build construction is expanding rapidly in the UK (driven by reduction of threshold u-values in Building Regulations), there are vast differences in the new-build and 'repair, maintenance and improvement' sectors. These differences warrant separate foci for investigation. The decision to examine the domestic building context in isolation has been a response to the uniqueness of its recent explosion of growth, its policy drivers and reports of problematic practices in the sector.

The inductive nature of this study has led to the discovery of numerous issues which – for practical reasons – could not be explored in greater depth. As far as possible, issues that were encountered repeatedly during the field study have been analysed comprehensively. Nevertheless, topics such as vocational education theory, energy and public policy, or innovation theory, might well have been included in analysis with greater attention, but limitations in scope have been necessary.

Another limitation of scope has been dictated by the natural evolution of field study; as 'gatekeepers' have granted access to projects and communities, by default other 'paths' in research have not been followed. For instance, it was highly difficult to find companies working on internal wall insulation (IWI), retrofitting outside of area-based retrofit projects, or in high-rise constructions. In light of this, such foci are largely absent from this research.

1.4 Thesis outline

Chapter 2 presents the context of research. It begins by describing UK housing stock and potential for improvement in energy performance and trends in insulation. It then describes the drivers and potential benefits of SWI retrofitting. Following this, scientific understanding of the principles of insulation and physical behaviours of insulated buildings is presented. This is joined by discussion of the risks of poor practice, both with regard to building fabric and occupant well-being. Best practice guidance and industry standards are then reviewed.

Chapter 3 begins with an overview of essential understandings of the SWI industry and of pre-existing knowledge about installation practices. It then discusses recent research of refurbishment and retrofit industries. Delineation is then made of the concept of 'quality', which provides the basis for much of the discussion in this thesis. This emerges from a multi-dimensional discussion which includes environmental impact, financial cost, social and economic impacts, craft and workmanship, management of work and pride and motivation. Lastly, a description is given of the research questions and the iterative process through which they were developed.

Chapter 4 presents the methodological bases for this research. It begins with a discussion of research strategy and a review of several traditions of inductive research. It discusses four traditions of research and provides an overview of several ontological and epistemological debates in social research, socio-technical and science and technology studies. The next section describes the application of research methods in this project. Finally, a description of analytical strategies and frameworks employed in the project is presented.

Chapters 5 and 6 present the results and evidence from field work. Chapter 5 begins by describing the organisation of reporting in the two chapters and the approach to selection of data for inclusion in the chapters. Chapter 5 contains results related to practices of installation and specification. Chapter 6 presents results in a range of themes related to factors understood to influence or provide context for practices.

Chapter 7 contains the discussion of findings. It begins by discussing the implications of research observations with reference to risks of unintended consequences. It then discusses the concept of 'quality'. Next, the context and implications of observations related to specification and installation practices are discussed. The context and implications of research findings related to a series of themes are discussed. This includes construction management, knowledge, understanding, skill, aptitude and motivation. A description of policy and its impacts on industry is followed by an examination of buildability, technical, techno-social and related analyses of employed technology. The chapter concludes with discussion of existing theory of professional systems and research which points to a need to imagine a new professional role in retrofitting.

Finally, Chapter 8 presents brief restatements of the research aim and main findings, the implications of findings, limitations of the research, and recommendations for further research. The chapter closes with a short conclusion to the thesis.

A glossary of terms is included in Appendix A. Unless noted otherwise, all photographs in this document were taken by the author during the course of this research.

2 Research context

2.1 Overview

This chapter presents a broad range of information and interpretation of literature to outline the context of the research. It starts with an overview of the UK housing stock and trends in SWI retrofit, before reviewing the principal drivers of retrofitting. It then describes the key potential benefits of SWI, before outlining the scientific principles of SWI and successful retrofit.

2.2 UK housing stock and trends in insulation retrofit

The UK has 27.3 million homes and its stock is among Europe's oldest and most energy inefficient. There are large quantities of Victorian, pre-Victorian, and inter-war properties still in existence – accounting for roughly half of the present stock, which can be interpreted from data shown in Figure 1.

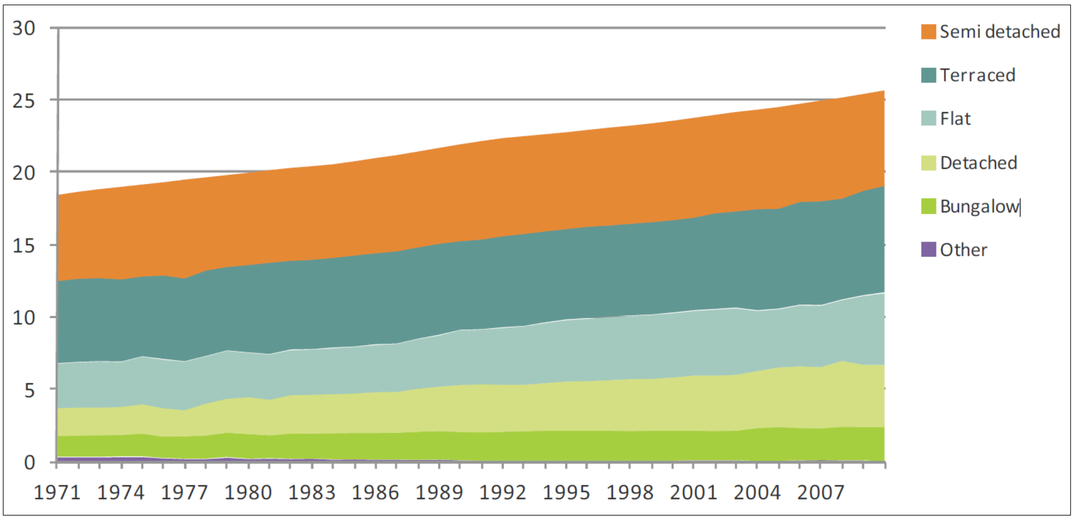

Figure 1: Housing stock distribution by age (millions) (Palmer & Cooper 2012, p.20). (Permission to reproduce original content granted by copyright holder)

The implications of this for energy performance are profound. Indeed, the majority of current UK housing stock was constructed before thermal building regulations even existed.

The explanations for this situation are too complex to engage with fully here, but to some extent relate to limitation of new development and redevelopment by planning and conservation laws and to generally higher cultural value and desirability of older properties.

The importance for future energy performance across UK housing stock cannot be understated. Projections indicate that roughly 80 per cent of 2050 housing already exists today -- around three quarters of which will have been constructed before 1975[3] (Committee on Climate Change 2010; English Heritage 2011). It is clear that to meet efficiency targets, energy refurbishment of millions of dwellings built before thermal building regulations will be required (Element Energy & Energy Saving Trust 2013).

[3] Thermal performance was first introduced in building regulations in 1965, but became more significant in 1976.

2.2.1 Typologies

As a general rule of thumb, roughly one-quarter of fabric heat loss is understood to occur through the walls of buildings. After loft and roof spaces, walls generally offer the most economical option for improving thermal performance of building fabric.

Nearly all walls in pre-thermal regulation housing either lack a wall cavity or have cavities unsuitable for insulating (e.g. Victorian era 'finger cavity' construction). A total of between 7.8 and 8.0 million UK homes have solid walls, and an additional 4.3 million are considered 'hard-to-treat' cavity construction (and so potentially suitable for SWI rather than cavity insulation) (DECC 2014a).

The two largest proportions of UK housing stock are comprised of terraced and semi-detached constructions (Figure 1). Compared to detached properties, these have a lower proportion of exposed external surface area. Flats -- having even less exterior surface -- comprise a less significant proportion of UK housing stock. Hence, terraced and semi-detached constructions are the focus of much SWI strategy.[4]

The practical implications of refurbishing building fabric in terraced or semi-detached dwellings (as opposed to in flats or detached housing) include potential access difficulties to rear gardens and 'building line' problems where one property is insulated, but an adjacent property is not. Detached properties present challenges to time and material efficiencies and retrofitting at scale. These implications are discussed further in Chapters 7 and 8. .

2.2.2 Tenure

Social housing accounts for roughly 18 per cent of UK homes by tenure (

Table 1, overleaf). In general, social housing can be targeted economically for SWI through area-based approaches since large numbers of homes are owned by single agents and are often co-located and of similar construction.[5] Hence, to date, area-based programmes have accounted for the majority of SWI retrofitting.

[4] Detached properties represent an increasingly significant proportion of houses, particularly as a result of new construction, but also a comparatively high retention of older detached properties. In light of continued tightening of energy performance standards, required u-values in the walls will be difficult to achieve with cavity insulation only given the limited space available for insulation. As a result, these properties are likely to add significantly to national total wall area requiring external or internal wall insulation.

[5] Many social housing properties suitable for SWI are system builds.

Table 1: UK dwelling stock profile, by tenure (in thousands of homes) (March, 2012) (Data extracted from: DCLG 2014, sec.Table 101)

Private sector		Social and public sector			Total dwellings
Owner occupied	Rented privately or with a job or business	Rented from housing associations	Rented from local authorities	Other public sector dwellings	
17,836 (64.2%)	4,920 (17.7%)	2,746 (9.9%)	2,189 (7.9%)	75 (0.3%)	**27,767** **(100.0%)**

Several other factors account for this trend. Social housing landlords typically engage in regular programmes of area-based general refurbishment and stock upgrading; this provides an obvious ‘trigger point’ for SWI. Furthermore, government quality standards for social housing stipulate baseline energy performance. Moreover, because social housing is generally occupied by lower income residents, programmes to reduce fuel demand provide funding for SWI. For all of these reasons, social housing is likely to remain an area of growth for retrofit in the foreseeable future.

Conversely, private rented housing stock – comprising nearly as much of the nation’s stock – is more heterogeneous, geographically distributed and held by many more owners. Many of the drivers for SWI retrofit in social housing are distinctly absent and there is a dearth of incentive to private landlords to invest in SWI. This has been reflected in low uptake of SWI in the private rented sector. Before it was recently scrapped, UK legislation had been expected by 2016 to obligate landlords to upgrade energy efficiency through the Green Deal when solicited by private tenants. This removed a potential driver of SWI retrofit in private rented housing.

Meanwhile, owner-occupied housing represents the majority of UK domestic stock, but like private rented housing it lacks many of the drivers of retrofit that social housing has. It also contains a higher rate of detached dwellings and hence requires more insulated wall area per dwelling. Although this might be seen as a strong rationale for use of SWI, it also necessitates a higher investment per dwelling. Furthermore, because ownership is essentially dwelling-by-dwelling, economies of scale from area-based programmes are more difficult to achieve. Government programmes to incentivise area-based retrofitting have, to varying extents, included owner-occupied housing. Under the Energy Company Obligation (ECO) (and formerly

Green Deal), support for SWI was extended to owner-occupied homes (see Section 2.3.5). Similar programmes are likely to continue to incentivise SWI retrofit in owner-occupied housing, although unlikely at the same rate as in social housing.

Although area-based programmes in social housing are dominant today, SWI will ultimately need to be rolled out across all sectors. This will mean that projects are likely to become increasingly complex; outside of social housing, heterogeneity of building typologies and configurations within neighbourhoods becomes more common, and as ownership shifts to occupants and private landlords, co-location and area-based projects will become more difficult to organise.

2.2.3 Potential for improvement in energy performance

It is clear that improvement to solid and hard-to-treat cavity walls offer significant potential for reductions in energy demand; however to date, there appear to be no robust published calculations of current or past UK average improvement in element energy performance from SWI. Nevertheless, ample evidence exists to understand a 'typical' improvement. A notional example of an enhancement from SWI retrofit would bring thermal conductivity of a baseline solid wall from 2.00 W/m^2K to a post-insulation conductivity of 0.35 W/m^2K.

Another way of assessing the impact of SWI retrofit is change in SAP; although this is a crude modelling tool, it is one of the few publicly available assessments of average or assumed improvement. The mean SAP rating for homes with 9 inch solid walls in 2008 was 43.3[6] Due to interdependencies of fabric and other factors, it is not possible to draw neat conclusions about improvements in SAP ratings from SWI, but guidance from an expert at Building Research Establishment (BRE) indicates that a small terrace with fair fabric efficiency might gain 5 to 10 points, while an inefficient detached house might gain 20-30 points (Nowak 2012).

The English housing stock in 2008 had an average 'Dwelling Emission Rate' value of 66.4 $kgCO_2/m^2$/year (corresponding to a SAP rating of 51.4) (DCLG 2014c). This is

[6] It should be noted that there is scepticism from many experts and heritage organisations about how appropriate the SAP models are for older houses. SAP takes account of many factors, including heating systems, fabric efficiency, construction type, and window orientation and sizes. Criticism of SAP is centred on three issues: the potential inaccuracy of assumed u-values for thick solid walls; the hygrothermal behaviour of vapour permeable materials (which when combined with impermeable insulants may become saturated or saturate the insulants and so perform much worse than expected); and occupant behaviour in older buildings, which may differ than that in modern buildings, in which users are expected to heat all spaces at a relatively constant rate.

somewhat lower elsewhere in the UK (the average SAP for UK homes in 2012 was 51.6) (Nowak 2012).

It is clear that whatever the future energy mix, government carbon and energy efficiency targets (Section 2.3.1) require huge gains in fabric efficiency. Acknowledging the low rate of demolition, without dramatic programmes of replacement or improvement severely inefficient housing will remain a high proportion of the UK stock; this points to the need for extensive roll-out of SWI to meet current targets.

2.2.4 Trends in levels of insulation

During the course of this research, explosive growth in SWI area has occurred; this forms an important context for this research. Despite this, the vast majority of solid wall properties remain uninsulated.

Many of the 'easy wins' in fabric efficiency across the national stock have already been gained. Of the UK's 27.3 million homes, the majority of potential in cavity wall and loft insulation has been attained (Table 2). Indeed, March 2014 estimates suggest that of the 5.0 million cavity wall homes that have not been insulated (26 per cent of all cavity wall homes), 1.4 million are considered to have limited potential (0.5 million of these are hard-to-treat)[7] and just 3.6 million are altogether uninsulated (2.9 million deemed hard-to-treat) (DECC 2014a, pp.34-35).[8] This leaves only 0.7 million 'easy to treat' cavities remaining to be insulated.

Table 2: Insulation levels in Great Britain housing stock and remaining potential to insulate, March 2014 (thousands) (DECC 2014e, p.34). **(Permission to reproduce original content granted by copyright holder)**

Insulation type	Insulated	Uncertainty*	Remaining potential**	Total number of properties
Cavity wall insulation	13.760 71%	480 3%	5,040 26%	19, 280 100%
Loft insulation	16,400	110	7,310	23,820

D

[8] DECC notes, "Although these properties are not fully insulated it is likely that they already have a relatively good thermal performance which means savings from having cavity wall insulation installed would be lower than for older properties. Limited potential properties are those built between 1983 and 1995 for England and Wales, and between 1984 and 1991 for Scotland" (DECC 2014a, p.35)

	69%	0.5%	31%	100%
Solid wall insulation	257 3%	126 2%	7,600 95%	7,990 100%

*Properties which may or may not be insulated
**Not all remaining properties will be suitable for insulating, either due to limited cost-effectiveness, limited energy-saving potential, or being hard-to-treat.

A very different reality surrounds solid wall properties; as of March 2014, at least 95-97 per cent (roughly 7.6 million) of solid wall properties were uninsulated (Figure 2). Historically, cavity wall and loft insulation have been prioritised over SWI in government policy due to lower cost and relative simplicity. A shift in policy began in January 2013 (with introduction of ECO and Green Deal), and solid wall properties have become a priority for investment in retrofitting.[9] SWI installations by funding source are shown in Figure 3 (overleaf).

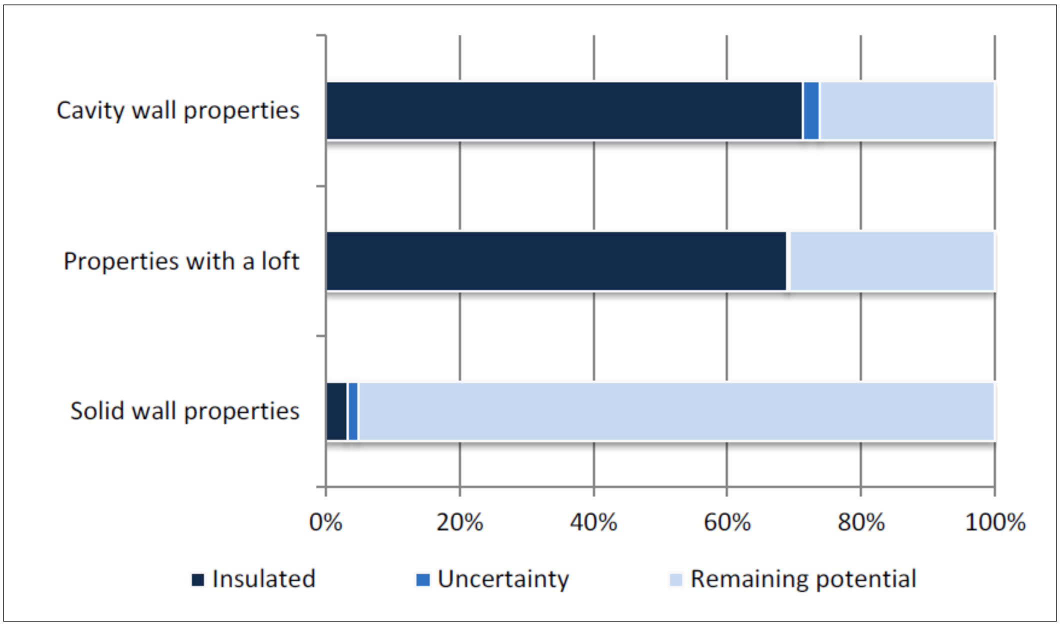

Figure 2: Remaining potential to insulate the housing stock in Great Britain, March 2014 (DECC 2014a, p.35). **(Permission to reproduce original content granted by copyright holder)**

[9] It is likely that a sizeable proportion of solid wall properties will not possible, or desirable, to treat with SWI. Reasons for this would include technical challenges, excessive cost of treatment, or historical or conservation area designations. DECC has announced plans to assess the likely degree of these limitations; however, no firm quantification of these challenges has been made to date.

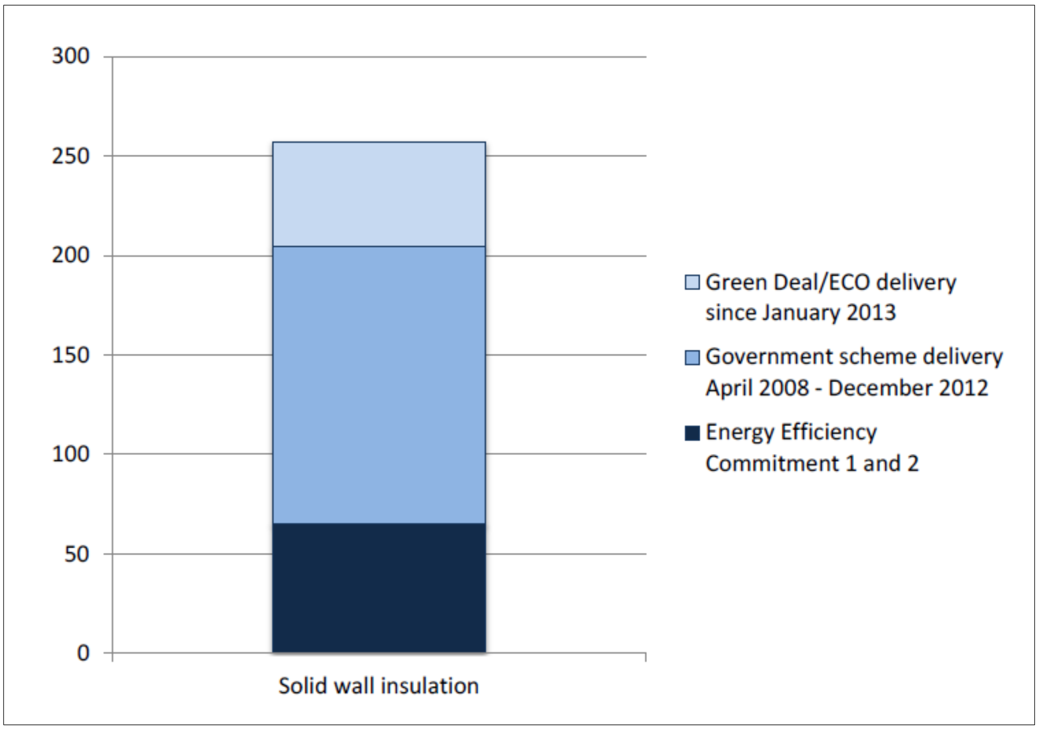

Figure 3: Number of homes in Great Britain with solid wall insulation by source, March 2014 (thousands) (DECC 2014a, p.34). **(Permission to reproduce original content granted by copyright holder)**

The number of SWI-treated properties in the UK today is roughly four times that just six years ago. At the start of this research (October, 2012), there were an estimated 99,000 insulated properties (u =126,000). During the 14-month period of field work for this research, the estimated total increased from 123,000 to over 204,000 (u =126,000) (DECC 2014d, sec.Table 2.5) (Figure 4). At the time of writing, there are an estimated 257,000 installations. Table 3 contains estimates of installations and remaining potential.

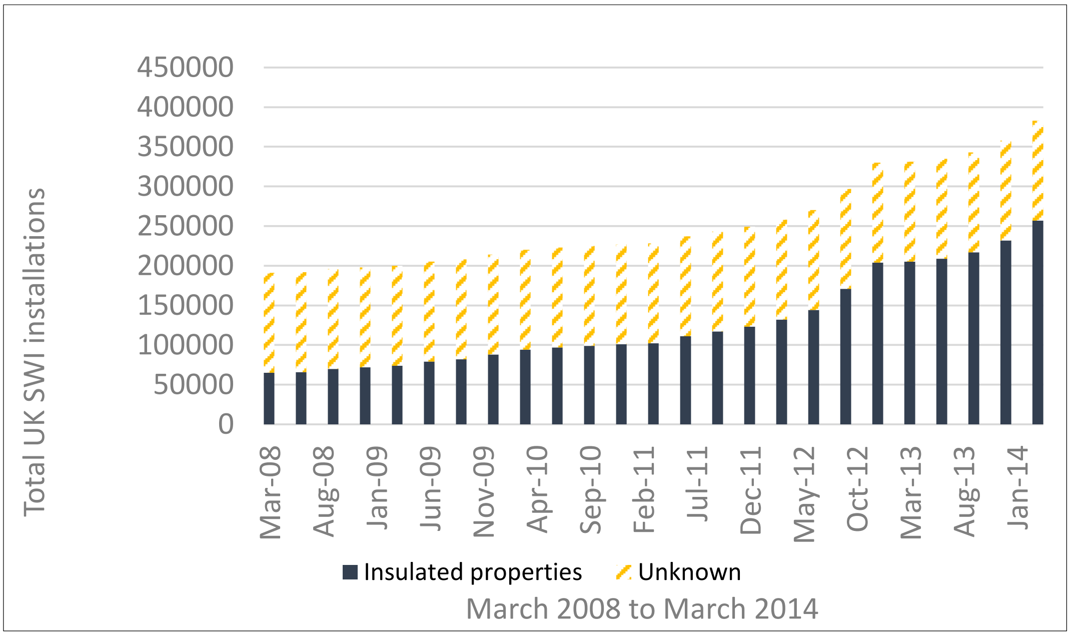

Figure 4: Cumulative installations of solid wall insulation in the UK: March 2008-January 2014 (DECC 2014d). **(Permission to reproduce original content granted by copyright holder)**

Table 3: UK Installations of solid wall insulation, March 2008 to March 2014 (thousands) (DECC 2014c, Table 2.5). (Permission to reproduce original content granted by copyright holder)

End of:	Insulated	Uncertainty*	Remaining potential**	Solid wall properties
March 2008	65	126	7800	7990
June 2008	66	126	7800	7990
September 2008	70	126	7790	7990
December 2008	72	126	7790	7990
March 2009	74	126	7790	7990
June 2009	79	126	7780	7990
September 2009	82	126	7780	7990
December 2009	88	126	7770	7990
March 2010	94	126	7770	7990
June 2010	97	126	7770	7990
September 2010	99	126	7760	7990
December 2010	101	126	7760	7990
March 2011	102	126	7760	7990
June 2011	111	126	7750	7990
September 2011	117	126	7750	7990
December 2011	123	126	7740	7990
March 2012	132	126	7730	7990
June 2012	144	126	7720	7990
September 2012	171	126	7690	7990
December 2012	204	126	7660	7990
March 2013	205	126	7660	7990
June 2013	209	126	7650	7990
September 2013	217	126	7650	7990
December 2013	232	126	7630	7990
March 2014	257	126	7600	7990

*Properties which may or may not have solid wall insulation

**Not all remaining potential properties are likely to be insulated because of cost, heritage and conservation, or technical feasibility

The reality remains that to meet UK GHG targets, the rate of installations will have to increase significantly (Figure 5).

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Figure 5: Solid wall insulation cumulative installations (2008-2022) (Committee on Climate Change 2013, p.118)

2.3 Drivers of SWI retrofitting

It is likely that impetus to retrofit may be rooted in more than one driver. For clarity of discussion, drivers are presented individually in this section. Order of presentation broadly follows national, building and occupant scales, then policy drivers and regulatory context.

2.3.1 Climate change and national emissions and energy targets

The critical importance of reducing human contributions to climate change has been asserted by the scientific community for many years. Recent conclusions suggest that the likely impacts of climate change include an increase in average global temperature of between 1.8°C and 7.1°C by the year 2100 and potentially devastating implications for humankind and ecology (Stocker et al. 2013; Committee on Climate Change 2014a; Committee on Climate Change 2014b). A significant risk of extreme and calamitous impacts exists if post-industrialisation GHG emissions levels remain unabated.

The UK Committee on Climate Change examined potential scenarios for reducing emissions and recommended that global emissions should peak by 2020 and at least halve by 2050 (relative to 1990 levels). Achieving this reduction would necessitate a 3-4 per cent annual reduction and reaching 20-24 $GtCO_2e$ by 2050. Projecting a global population of around 9 billion in the year 2050, this reduction would equal 2 tCO2e per capita in 2050. In response, the Committee determined a UK reduction target of 80 per cent by 2050. (Committee on Climate Change 2014b)

Approximately 66 per cent building emissions (roughly 24-29 per cent of total UK emissions, depending on year and calculation method) come from residential buildings (Figure 6, overleaf) (Committee on Climate Change 2013).

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Figure 6: GHG emissions from buildings in the context of total UK emissions (2012) (Committee on Climate Change 2013, p.110)

Recent statistics indicate that heating buildings accounted for 38 per cent of total UK CO_2 emissions, and 32 per cent of GHG emissions in 2009 (DECC 2012a, p.3). Nearly half (48 per cent) of heating-related GHG emissions stem from the domestic sector (DECC 2012a, p.4). Nearly two-thirds (64 per cent) of domestic GHG emissions stem from space heating (Table 4; Figure 7, overleaf).

Table 4: Heat-related GHG emissions ($MtCO_2e$) in the UK domestic sector, by end-use and fuel-type (data from DECC 2012a, p.3). (Permission to reproduce original content granted by copyright holder)

End-use/ $MtCO_2e$	Gas	Oil	Solid fuel	Electricity	Total
Space heating	46.2	7.0	2.7	8.1	64.0
Water heating	13.5	1.5	0.2	3.3	18.6
Cooking/catering	1.4	0.0	0.0	2.9	4.3
Total	61.0	8.6	2.9	14.4	86.9

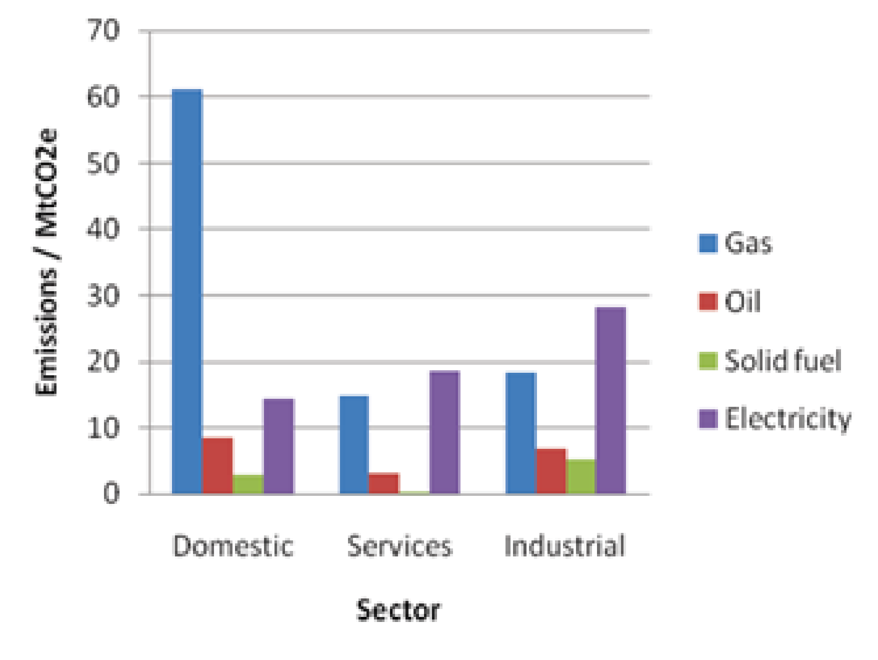

Figure 7: Heat-related GHG emissions in the UK, by sector and fuel (DECC 2012a, p.4). (Permission to reproduce original content granted by copyright holder)

Nearly three-quarters of GHG emissions (73 per cent) from domestic buildings are related to space and water heating (DECC 2014b).[10] Strikingly, heating domestic buildings comprises the dominant source of national emissions: accounting for roughly 20 per cent.

The reality is a stark one: our built environment is a major contributor to climate change and insulating the vast majority of highly energy-inefficient solid wall (and hard-to-treat cavity) properties which together make up roughly 12.3 million of our 27 million homes is critically important to reducing national GHG emissions. To reach the 2050 carbon reduction target, indications are that 600,000 UK homes must be refurbished each year "to a high degree of thermal performance" (Energy Saving Trust 2010b, p.2).

2.3.2 Rising cost of energy, and household expenditure on thermal comfort

Arriving at a neat monetary cost of maintaining thermal comfort in homes is difficult, but costs are clearly significant.[11] Domestic wholesale cost of fuel offers a simple -- but useful -- metric for comparison of energy cost over time.

[10] Also shown in Table 4 is that the heavy contribution from the domestic sector is not significantly attributable to the use of high-carbon fuels, as nearly three-quarters of domestic emissions are from the use of gas.

[11] Multiple considerations need to be made when assessing the real cost of energy supplied to homes for heating. First, an estimated disaggregation must be made between the energy spent on heating and cooling and unregulated loads and other uses of energy in homes. Second, tabulation must be made of fuel prices and the split of which fuels are used for

Figure 8 shows increase in domestic UK prices (in real terms) of gas, electricity, and solid fuels between 1996 and 2013. These data show that prices have grown substantially (a near doubling in the case of gas) over the past 17 years (DECC 2014e, fig.2.1.2).[12]

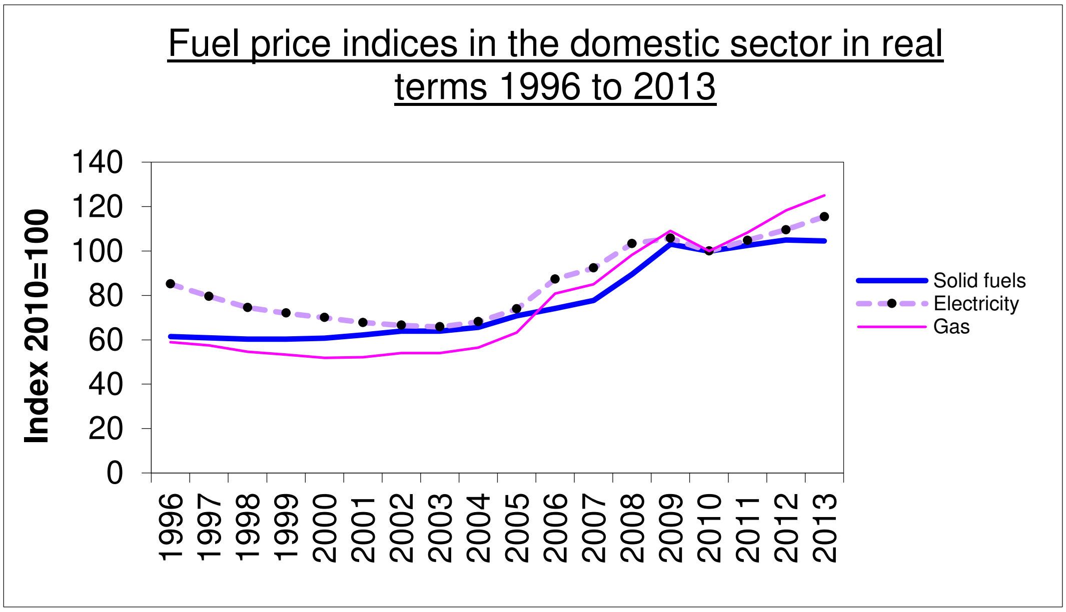

Figure 8: UK Consumer Prices Index: fuel components in the UK relative to GDP deflator (DECC 2014e, fig.2.1.2). (Permission to reproduce original content granted by copyright holder)

The increase over time in fuel price to households is reflected in the growing presence of the issue in national political debate and campaigning. Despite gradual improvements in the thermal performance of UK building stock, expenditure on heating is increasingly discussed in popular media (Daily Mail Online 2015; The Guardian 2013; Uswitch 2013).

2.3.3 Fuel poverty

Expenditure on fuel presents a significant difficulty for many millions of households in the UK. Household income has clear relevance here, but so too does energy price and

heating in which homes (including in which Public Electricity Supply region). Furthermore, a correction for temperature and other climate data (e.g. insolation) needs to be made. Occupant behaviour, fabric efficiency, and services efficiency also each factor importantly into how much energy is required to maintain thermal comfort. Finally, the price of domestic supply obviously depends on which supplier and which tariff is paid by the householder.

[12] This conclusion draws on data gathered by DECC through its quarterly Domestic Fuel Inquiry survey across all Public Electricity Supply (PES) regions. It accounts for the ‘Big Six’ energy suppliers and approximately 95 per cent of the market. The survey covers both electricity and gas prices. It contains prices for each tariff and the number of consumers subscribed to each. It combines the variable cost per unit of fuel with the fixed cost per day, factors in any relevant discounts and uses a fixed annual consumption per household (3,800kWh for electricity and 15,000kWh for gas in 2013) to estimate bills in annual terms. (O’Neill & Trewin 2014) DECC also uses the Consumer Prices Index (CPI), which is published by the Office for National Statistics, to calculate quarterly data on fuel price indices in real terms.

efficiency of building fabric and services. The impact for millions of low income households in the UK is severe. This has been shown by many authors, including important work by Boardman (2012; 2010).

Many measures exist for assessing the impact of fuel expenditure on low income households. The terms 'fuel poverty' and 'fuel poor' are general terms used to describe severe impact and have various definitions. England and the Devolved Administrations have made separate statistical assessments and in part utilise different criteria.[13]

Despite many years of ambitious national legislation and government targets aiming to eliminate or dramatically reduce fuel poverty, efforts have broadly failed to achieve meaningful reductions. Data produced by DECC (2014c) show that between 2003 and 2012 the overall proportion of fuel poor households increased and decreased by roughly 10 per cent twice (having fallen in the past two years), but the average fuel poverty gap increased in real terms from £254 to £443.

Approximately 2.28 million (10.4 per cent) of English households and 328,000 (33 per cent) of Welsh households were in fuel poverty in 2012. Although fuel poor households generally decreased over the preceding four years in England, they increased in Wales. It is difficult to isolate causal factors in changes in fuel poverty; however, data show a strong correlation between falling household income and rising rates of assessment as fuel poor, and between changes in indicated energy efficiency and fuel poverty. Forty-one per cent of 2012 English households in the lowest income decile group were fuel poor and 36 per cent of those in the second income decile group were. Fuel poverty is strongly correlated to building energy efficiency (assessed by SAP) (DECC 2014c, p.5; Welsh Government 2014b). Figure 9 (overleaf) shows DECC (2014c, p.31) data reflecting rates of fuel poverty in England (by low income high cost indicator) against SAP bands. This shows that fuel poverty

[13] Fuel poverty in England is currently assessed using the Low Income High Costs (LIHC) definition. According to this, a household is considered to be in fuel poverty if its required fuel costs are above the national median and if to meet these costs the household would have residual income below the official poverty threshold. In Wales, where much of this research project was situated, fuel poverty is defined as expenditure of 10 per cent or more of household income (including Housing Benefit, Income Support or Mortgage Interest or council tax benefits) on energy costs. Collection of statistical data on levels of fuel poverty is less robust in Wales than in England. Available information is from the Wales Fuel Poverty Projection Tool, which estimates changes in levels of fuel poverty since the 2008 Living in Wales survey. The tool accounts for household income, fuel costs and installed energy efficiency measures. Projections for 2012 show 30 per cent of Welsh households in fuel poverty (386,000 households), an increase of 54,000 households from 2008. Projections also showed that for 2012, 33 per cent of vulnerable households (328,000) were in fuel poverty. The Welsh Government reports that energy efficiency measures installed from 2010 to 2012 has reduced by 3 per cent (36,000 households) the number of households in fuel poverty. (Welsh Government 2014b).

decreases dramatically with higher SAP ratings. Thirty-five per cent of households in G rated construction were fuel poor in 2012 against two per cent living in A/B/C rated and seven per cent living in D rated constructions. DECC (2014c, p.31) explains that "The average fuel poverty gap is higher for households living in properties in bands A/B/C than households living in properties banded D or E as incomes for fuel poor households in this group are generally lower by comparison."

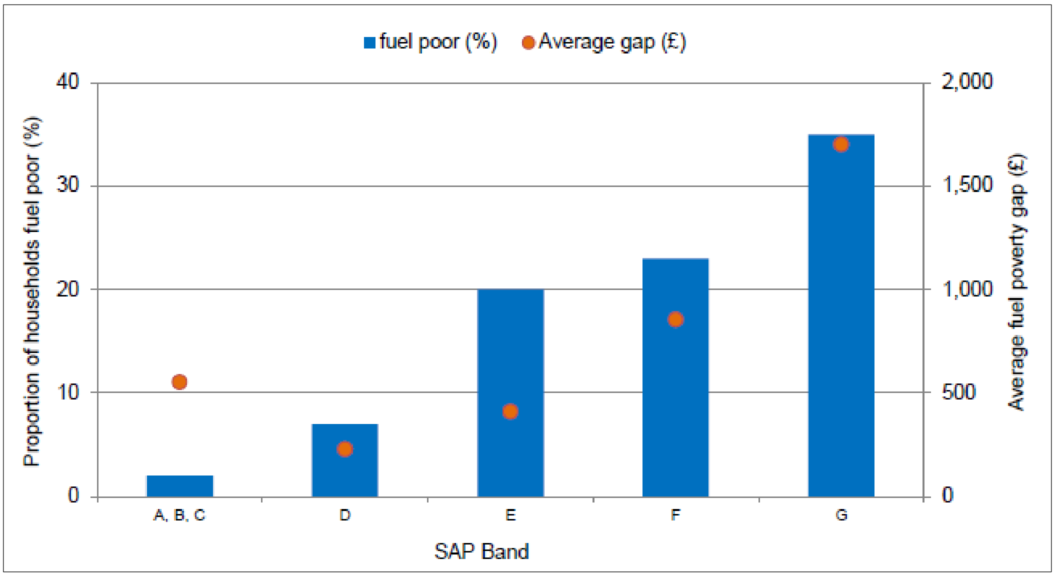

Figure 9: Fuel poverty and average fuel poverty gap in England by SAP rating bands, 2012 (DECC 2014c, p.31). (Permission to reproduce original content granted by copyright holder)

As discussed in Section 2.2.3, it is difficult to correlate neatly SWI retrofit to change in SAP rating.[14] Nevertheless, SWI offers clear potential improvement of thermal performance. This may lead to improved thermal comfort, but may in fact carry implications for change in expectations for thermal comfort (Oreszczyn et al. 2006a) and thus might actually negate some of the expected reductions in energy use (Tweed 2013). Other evidence suggests that cavity and loft insulation can reduce fuel consumption associated with space heating by 10 per cent in centrally heated properties and 17 per cent in non-centrally heated properties (Hong et al. 2009).

Nevertheless, improving energy performance with SWI offers a range of important benefits and it is vitally important that when SWI is employed, if follows appropriate and effective specification and installation practice to realise potential gains.

[14] Typical improvements to SAP ratings from SWI range from 5 to 15 points

2.3.4 Property improvement and value

2.3.4.1 Definition of value and the role of financial insurance

Buildings are generally the most valuable of our properties. Their value may relate to build-quality, geographic location, cultural or 'intrinsic value', or a range of other determinants.

Defining 'intrinsic value' can be an elusive exercise. Often in buildings it does not correlate to monetary value. It is clear that to many, Victorian and pre-Victorian properties hold high cultural value. These properties comprise a considerable proportion of UK stock (pre-1919 constructions comprise over one-fifth currently) (Palmer & Cooper 2012). There is an even greater proportion of our stock, however, which are old (but not historic), highly energy inefficient and which lack obvious cultural value. Yet to many, they retain important intrinsic value. At neighbourhood or dwelling scales, these buildings may be intrinsically valuable.

It is useful to recognise that solid wall and hard-to-treat properties lie across a wide spectrum of monetary and cultural value. At one end of this spectrum, desirable properties with high 'intrinsic value' attract investment in general refurbishment to maintain their high value. At the other end, investment may offer the hope of improving value. At both ends of the value spectrum, SWI offers a mechanism by which inefficient homes can be brought in line with efficiency and performance policies for the built environment. To achieve this, however, it is critical that SWI performs as anticipated and without unintended consequences.

Moreover, adequate financial guarantees should ensure that property value is protected against any potential unintended consequence arising from inappropriate practice. The delivery of SWI through policy instruments is insured financially through third party providers. These providers function at arm's length from the industry, but furnish vitally important security in investment in SWI and the retrofitted homes. The topics of latent defect insurance (which covers workmanship), product guarantees and financial underwriting of insurers, as well as study of insurance agents involved in SWI -- while not a focus of this research -- are examined in the findings and analysis of this research.

2.3.4.2 Intrinsic value and subjective decision-making

The question of whether to knock down or refurbish buildings has been debated by many authors (Plimmer et al. 2008; Boardman 2010; Boardman 2012; Energy Saving Trust 2010b). Beyond considerations of build-quality, energy efficiency rating, health and thermal comfort factors (Roys et al. 2010; Davidson et al. 2011; Davidson & White 2010; Davidson et al. 2012), decisions about refurbishment frequently hinge on intrinsic value of properties. Plimmer, et al. (2008) argue that although refurbishment is more sustainable than rebuilding, a range of obstacles exist which include difficulty in determining social valuation and a lack of tools and proven methodologies for assessing environmental impact and life cycle cost. Intrinsic value reflected in decisions is difficult to predict and is largely subjective. Subjectivity drives not just the decision of whether or not to retrofit, but often how to respond to aesthetic value, cultural heritage, or conservation ethos.

Discussions with experts in early stages of this research highlighted a perception that a disproportionate amount of research and commercial activity has focused on refurbishment of pre-1919 properties. In recent years, for instance, significant research at BRE reflects this trend (Ferguson 2011; Cartwright et al. 2010; Yates 2006). While this research has been valuable, it is important to expand the focus of retrofit research in the context of post-1919 properties and housing with lower objective cultural value.

2.3.4.3 Quality standards, thermal comfort and damp

The inefficiency of UK housing stock reflects the reality of an aging housing stock, largely constructed before the introduction of modern standards of building. Heating cost as a trigger of SWI has already been discussed, but there are important implications of aging housing for thermal comfort, damp and human health.

It is difficult to assess thermal comfort across housing, but one measure is compliance with the Decent Homes standard. In England (which has a comparatively modern stock in the UK), recent reporting suggests that 22 per cent of homes (4.9 million) failed to meet the Decent Homes standard (DCLG 2014c, p.42). A lower fail rate related to thermal comfort was found in social homes: 15 per cent of private rented homes failed on this basis, compared to 5 per cent of homes in the social sector (DCLG 2014c, p.43). English homes in the social rented sector are generally more energy efficient than those in the private sector – with an average SAP rating in the social sector of 64.6 compared to 57.4 in the private sector (DCLG 2014b, p.12). This parallels much higher levels of non-cavity walled homes insulated with SWI: 16 per cent of those in the social sector as opposed to 3 per cent in the private sector (DCLG 2014b, p.20). It may also be attributable to the fact that 29 per cent of homes in the private sector are built with solid wall construction as opposed to 13 per cent in the social sector (DCLG 2014b, p.42).

Marked reduction in the number of UK homes with damp problems appears to have occurred in recent years. According to the 2012-2013 English Housing Survey, an estimated 970,000 homes (4 per cent) had “some problems with damp” in 2012, compared to 2.6 million (13 per cent) in 1996. Of these homes, 604,000 were categorised this way due to condensation and mould (DCLG 2014c, p.44). The

Scottish Government (2016) reports just 4 per cent of Scottish homes with dampness and 9 per cent with condensation in 2012, against 8 per cent with dampness and 21 per cent in 1996. Data from Northern Ireland is difficult to interpret as the Northern Ireland House Condition Survey aggregates thirteen markers of unfitness for habitation into its Fitness Standard. In 2011, dampness was not among the three most common reasons for a classification as unfit, while in 2009 it was the third most common (Northern Ireland Housing Executive 2013, pp. 48-49). The Survey estimated that 35,200 dwellings (4.6 per cent) were statutorily unfit in 2011, against 21,600 (4.9 per cent) in 2011 (Northern Ireland Housing Executive 2013, p.48). It should be noted that the devolved administrations collect housing data independent of the English Housing Survey and no published comparison of methodologies has been found. Data for Welsh housing since 2008 is provided by the National Survey for Wales, but this does not include property surveys. Government data collected in 1998 (Welsh Government 1998, p. 7) indicated that 17,000 (10.3 per cent) of Welsh houses were "unfit" due to dampness.

Despite relative successes in thermal comfort and damp across homes in the UK, these issues remain as stark challenges. SWI -– when specified and installed appropriately -– can improve thermal comfort, mitigate damp problems and alleviate impacts on health of occupants. There is clear evidence of a need for properly installed and specified SWI retrofits in the UK's older stock. Topics of thermal performance, moisture and human health are discussed further in Section 2.5.

2.3.5 Policy, legislation and regulatory context

2.3.5.1 Policy and legislative drivers of SWI retrofitting

Policy and legislation are central drivers of contemporary SWI retrofitting.[15]

Following broad moves toward liberalisation in energy markets made by the Conservatives during the 1980s and early 1990s, Government policy today has limited direct power to control source emissions and so utilises subsidy, taxation, incentives and planning legislation as mechanisms to reduce energy demand.

The dramatic growth in SWI retrofitting captured in this research relates largely to several policy instruments. Most observed projects were in area-based schemes funded through ECO, and to a lesser extent, the Community Energy Savings

[15] Energy policy in the UK primarily follows the 2012-2013 Energy Bill, the 2008 Climate Change Act, the 2007 Energy White Paper and 2009 Low Carbon Transition Plan. DECC leads in administering policies, which at present focus on improving the energy efficiency of building stock and on reforming the electricity market. Earlier policy followed the 2003 Energy White Paper and the 2006 Energy Review Report.

Programme (CESP), the Carbon Emissions Reduction Target (CERT), and Arbed. Other projects undertaken by organisations in this research -- but not directly observed -- fell under the Green Deal and Nest programmes. These programmes are (or were) major mechanisms for leveraging public and private investment into housing stock improvement. Further details of the scope, source of funding, stated aims and legislation relevant to each of these instruments can be found in Appendix B

2.3.5.2 Regulatory context

SWI work in the UK is subject to building regulations. Of particular relevance is Part L1b which stipulates u-values for insulated elements and dictates trigger points for 'consequential improvement' in building refurbishment.[16]

Workmanship is regulated under Regulation 7 of the Building Regulations. A range of European and International Standards for practice, workmanship and product certification underpin the building regulations as well as technical approval standards.

The EU Energy Performance of Buildings Directive (EPBD) requires the production of Energy Performance Certificates (EPCs) for all domestic properties under certain conditions.[17] EPCs may serve as a trigger point for SWI, since improving energy efficiency ratings may be an incentive or requirement in various contracts, funding arrangements or organisational policies.

Further details of regulatory context can be found in Appendix B.

[16] Building Regulations fall under the scope of the Secure and Sustainable Buildings Act 2004, this amends the UK Building Act 1984.

[17] EPCs are required in domestic (as well as commercial and public properties) whenever they are sold, built or rented, or when converted to fewer or more units, or changes are made to HVAC systems. EPCs contain an energy efficiency rating of a property, which is computed using the RdSAP methodology.

2.4 Potential benefits of SWI retrofitting

In addition to direct drivers of retrofit, SWI offers potential benefits to owners, occupants, and society when it has been specified and installed according to best practices. In some cases, these benefits may in fact be drivers of retrofit projects, but they are presented here separately from more typical drivers.

2.4.1 Improved thermal performance and health

Strong correlations have been drawn between improved energy efficiency and health. Research by Washan et al. (2014, p.32) cites evidence which suggests that cold-related health impacts cost the NHS approximately £1 billion or more annually. Wilkinson et al. (2005) compared questionnaire results from 3,400 dwellings in the Warm Front programme to temperature measurements in 1,600 of these dwellings and found that common mental disorders decreased with increasing indoor temperatures. They also found that risk of cold-related mortality fell with increasing energy efficiency. Critchley et al. (2007) also examined data related to Warm Front improvements and found that despite improvements to heating systems, many occupants in pre-1930 properties (presumably without SWI) remained dissatisfied with thermal comfort. They found correlations between colder homes and higher rates of long-standing illness, disability, and likelihood of anxiety or depression.

2.4.2 Building-scale adaptation to climate change

Evidence suggests that even if swift and comprehensive action is taken toward reducing atmospheric GHG, a threshold has already been crossed toward irrevocable warming and climate disruption (IPCC 2014). Therefore, we will need buildings to interact with different climate conditions than they were originally designed against.

The UK built environment is poorly suited to confront the risks of overheating, flooding and reduced water availability posed by climate change. Walsh, et al., (2007) highlight the importance of understanding the vulnerabilities of engineering systems in order to be able to make them more robust and resilient. UK housing has few features to limit overheating (e.g. small shuttered windows on south and west facing walls, exteriors painted white to reflect heat, courtyards with vegetation or water to temper the immediate environment. BRE (2004) suggests that with increased severity and frequency of flooding, buildings will need to be capable of being reoccupied more quickly and at lower cost. It notes that traditional construction materials are likely to be susceptible to deterioration during periods of higher temperatures and with longer hotter periods. They may also be subject to new thermal movements and movement in foundations due to increased variability in wetness. This movement may reduce tightness to air, water, and vapour (Al-Homoud 2005) as well as lead to increased cracking in concrete, masonry and finishes (BRE 2004). Higher levels of driving rain may lead to wetter materials which are more susceptible to frosts; increased weather tightness may be necessary due to anticipated increased severity of winter and rainfall (Committee on Climate Change 2014).

If specified and installed appropriately, SWI retrofitting can potentially minimise vulnerability of occupants and building fabric to increased severity of weather; however without careful specification, SWI may instead exacerbate summertime overheating and reduce the drying potential of building fabric (Section 2.5).

Rather than simply targeting *en masse* application of SWI to our housing stock, an intelligent strategy for retrofitting would incorporate careful study of options, risks, and trade-offs of various strategies for SWI. This might trigger rethinking the configuration, design or specification of insulation - and indeed even the suitability or desirability of applying SWI in some limited situations in the first instance. A model of climate-change adaptation and risk management which responds to multiple feedbacks (

Figure 10) was recently presented by Field, et al. (2014, p.9).

Figure 10: Climate-change adaptation as an iterative risk management process with multiple feedbacks. People and knowledge shape the process and its outcomes (Field, et al. 2014, p. 9)

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SWI specification should respond to evolving evidence, to analysis of our changing climate and be flexible, iterative, and responsive to new evidence. Specification should never adopt a 'one-size-fits-all' approach.

2.4.3 Economic and social sustainability

Successful SWI practice should be understood as relevant not just to energy and climate change, but also to other aspects of environmental, social and economic sustainability (Brundtland 1987).

By reducing financial expenditure on energy in any household, logic suggests that income is conserved and financial resilience to stress factors is improved. This brings stability to households and improves resilience to the effects of climate change and other stresses. Job creation, stimulation of regional economy, and vocational skills development are important potential co-benefits of SWI retrofit programmes, just as they are in any major infrastructure development. As a significant improvement of energy efficiency, SWI potentially bolsters other aspects of sustainability by reducing resource depletion and pollution, improving local and non-local air quality and reducing the demand for fuel distribution infrastructure.

2.4.4 Improved protection of building fabric from weather

Correctly installed EWI provides overcladding and raises the fabric above freezing temperatures in winter, hence eliminating risk of spalling. When installed and maintained correctly greatly, fabric moisture accumulation is minimal. This, and dramatically reduced temperature gradients across elements and minimised diurnal and annual variations, significantly reduces material stresses.

If EWI is not specified, installed and maintained appropriately, many routes of moisture transport (e.g. faulty or blocked rainwater goods, failed flashings, ground moisture, and condensation) remain problematic, and are perhaps exacerbated by the presence of the retrofitted system preventing drying. This can lead to severe damage. These topics are discussed further in Section 2.5.

Noise attenuation resulting from introducing layers of insulation and render or drywall to building fabric may improve occupant comfort as well as reducing sleep disruption and daytime environmental stress. Although this is not a notable driver of SWI retrofit, it is a clear benefit of installation. SWI alters the aesthetics of older housing, which may have surfaces in poor condition. Many would argue that this is not inherently a positive impact. Nevertheless, appropriate SWI practice offers the potential for increased property values and neighbourhood regeneration, particularly where outside surfaces are in poor condition prior to external retrofit. SWI can in these cases refresh the outside appearance of properties which may provide a considerable ancillary aesthetic benefit. In turn, this may extend the lifespan of buildings, thereby saving significant quantities of resources.

2.5 Principles of solid wall insulation

2.5.1 Materials, products and configuration

2.5.1.1 Materials and products in mainstream use

A range of insulants are used in SWI; these have significant differences in performance in use and embodied environmental impact (Hall 2010; Energy Saving Trust 2010a; CIBSE 2007; Baker & BRE 2013). Other variations include firmness and resilience, internal structure, vapour permeability and moisture retention.

Although technological advances have been made in insulation materials, the majority of today's materials have been used for several decades -- largely unchanged. These include:

- polyurethane foam (PUR), board or sprayed;
- polyisocyanurate (PIR), board or sprayed;
- mineral wool;
- glass fibre
- expanded polystyrene (EPS);
- extruded polystyrene (XPS);
- phenolic foam;
- polyethylene foam; and
- cementitious foam.

The vast majority of projects observed in this research employed EPS or mineral wool boards. Others employed phenolic and PIR foam boards.

In addition, other materials are employed in varieties of SWI systems (direct-fixed, spray-applied, battened, rainscreen [EWI], and studded [IWI] installations). Nearly all projects observed employed direct fixing.

Although the materials required differ for various systems, typical materials include:

- parge coats;
- plaster/render beads;
- fibreglass mesh;
- sill extensions, caps, flashing;
- adhesives;
- fixings;
- render;
- plaster;
- drylining;
- vapour control layers (VCLs);
- timber and fixings for enabling works;

- paints and anti-mould growth linings;
- extensions for plumbing, drains, flues, electric, or other services;
- wood fibre, laminate, or cement fibre boards; and
- silicone sealants.

2.5.1.2 Niche market and near-market insulants

The limitations of dominant products in the insulation marketplace include insulative performance, diminishing performance over time, difficultly in achieving contiguous performance across boards (loss of performance near edges), poor vapour tightness at joints, low vapour permeability (where high permeability is desirable), high embodied energy, pollution, toxicity, resource intensity in manufacturing, and unsustainable end-of-life options.

There are numerous alternatives to the 'mainstream' materials -- including technically-advanced products and traditionally-employed or natural materials. A brief overview is contained in Appendix C.

Advanced materials offer potential for reducing energy demand in building fabric at low material thickness or high compressive strength. Because they are new to market and in many cases use rare or expensive materials or manufacturing methods, they are generally expensive. They also suffer from a lower evidence base for service life and performance in use.

'Traditional' and 'natural' materials have benefits including low material toxicity, high vapour permeability or vapour buffering potential, sustaining local or agricultural economies, ease of reuse or repurposing at end-of-life, and potential for low embodied energy. However, because their point of origin may be far from building sites, long transport distances may be required compared to mainstream products.

2.5.1.3 Internal or external insulation: decision factors

In almost every instance, SWI will only be applied to either the internal or external face of the wall. A hybrid approach may use IWI and EWI on alternate walls. This is often employed in conservation areas where preserving original façades is desirable. It is also often employed in IWI projects with kitchens and baths on one elevation to save costs associated with remodelling these spaces. As the imperative to reduce energy demand is likely to deepen as society continues to move toward climate change mitigation policies, it is likely that many cavity wall properties will be insulated with SWI (even where cavity insulation has already been installed) in order to further reduce building energy demand. A principal consideration in deciding which face to insulate is likely to be cost, which will be impacted not just by product costs (EWI systems typically include more material and are more expensive), but also the need for remedial or enabling works, post-retrofit refurnishing (e.g. in kitchens or bathrooms), or access requirements such as scaffolding.

Other factors include ease of installation, disruption to occupants, implications for performance, protection of building fabric, compliance with planning[18] and conservation area legalities, and aesthetics. Costs for IWI are generally lower per unit area than EWI. This should be contextualised against loss of habitable space from IWI and the potentially greater improvement in performance and fabric protection from EWI. As discussed elsewhere in this thesis, there is significant potential for unintended consequences in both IWI and EWI.

An overview of these and other factors is given in Table 5 (overleaf).

[18] As of 2012, planning permission for typical EWI installations is no longer required.

Table 5: A comparison of external versus internal wall insulation: advantages and disadvantages

	Internal	External
Installation	**Advantages** • Ease of installation: no scaffolding not typically required, installation is not delayed by bad weather • Can be installed room by room **Disadvantages** • Insulation should be installed within joists and rafters to eliminate temperature differential. Involves access by floor or ceilings, hence is sometimes omitted. If omitted then heat loss occurs, may lead to condensation, mould and/or rot. • Disruption to occupants to allow clear access to the external walls, temporary disconnection of services • Noise, dust and debris will be generated inside dwelling • Window/door reveals must be insulated to stop condensation • Kitchens and bathrooms particularly problematic as refitting of fixtures, tiles, etc. likely to be required • Problems with penetrating or rising damp not solved by installation and must be fixed first • Removal of plaster, plasterboard, or drylining likely to be required prior to installation	**Advantages** • Insulation not required to be installed within the first floor as the external wall insulation covers the edge of the floor automatically • Can be applied with less disruption to the household than internal insulation as work is external to the property and does not require access to the inside of the property **Disadvantages** • Windows and doors may need to be moved outward • Eaves extension may be required • Flashing or capping required • Likely to require sill extensions, introducing potential for moisture ingress in instances of material or design failure • Minor ground works may be required to insulate below ground (recommended to insulate to base of foundation) • Requires good access to the outer walls • May require relocation of drains or other services • Removal of rendering may be required if not sound

Incidental impacts	**Disadvantages** • Likely to require the removal and possibly replacement of skirting boards, coving and cornices, window and door trim, electrical fittings, radiators and pipe work • Lose of internal space may necessitate new furniture	**Disadvantages** • Likely to require the removal and possibly replacement of water goods (e.g. guttering, downpipes), boiler flues, electrical services, satellite dishes, other services, and external fittings (e.g. plant hangers, trellises) • Damage to landscaping is possible
Performance	**Advantages** • Improves sound resistance • Reduces accidental infiltration **Disadvantages** • Wall will be exposed to the elements and it will become colder, therefore it is possible that spalling or degradation of the outer surface or brick mortar pointing will be accelerated • U-values are limited by the space available to install the system • Risk of interstitial condensation due to high temperature gradient between insulation and wall or adjacent elements.	**Advantages** • Improves sound resistance • Little restriction of u-value as the insulation can be ≤300mm • Minimal risk of interstitial condensation as external insulation elevates wall temperature (except at perimeters of insulation in terraces) • 'Breathable' systems may allow for the drying of water vapour • Insulation covers entire wall and eliminates cold spots • Reduces accidental infiltration Can increase the life of walls by protecting them from weather **Disadvantages**

		• If not breathable system, and in the absence of VCL, may contribute to vapour accumulation and humidity problems
Cost	**Advantages** • Is generally cheaper to install than external wall insulation • IWI is easier to maintain than external insulation **Disadvantages** • Will slightly reduce the floor area of any rooms in which it is applied – typically IWI systems are 70 – 130mm thick	**Advantages** • No reduction in the available living space **Disadvantages** • Typically higher cost)
Other	**Advantages** • The external appearance of the building is maintained so it can more easily be installed in accordance with planning or conservation areas restrictions **Disadvantages** • Can make it hard to fix heavy items to inside walls – although special fixings are available	**Advantages** • Renews the appearance of outer walls **Disadvantages** • May require planning permission • Limited opportunities in conservation areas • Loss, or need for replacement of, exterior aesthetic details

2.5.2 Physical behaviours and implications for risks of performance gaps and unintended consequences

A brief overview of risks is provided in this section and in Section 2.5.3. A more comprehensive review is available in work by Forman and Tweed (2014).

2.5.2.1 Conduction, convection and radiation

Conduction

Important impacts of SWI practice related to conduction include moisture content and thermal bridging.

Increased conductivity due to excessive moisture in insulation or other areas of the SWI system or wall element presents potential for significant performance gaps.

Thermal bridging, or conductive loss through uninsulated or under-insulated areas, results in undesirable heat transfer and temperature gradients. In SWI, this most commonly occurs at junctions with:

- slab or foundation walls;
- floors;
- roofs;
- abutting walls;
- projecting elements such as porches, or garden walls;
- services;
- fixings; and
- windows and doors.

The impact is two-fold: firstly, a route for heat loss exists; and secondly, it will likely present a sharp temperature gradient and so introduce a point of condensation risk. Although thermal bridges are difficult to eliminate completely (particularly in IWI), there are strategies for reducing temperature gradients and their correlated risks.

Convection

Air movement occurs in response to pressure differentials, which in buildings may be caused by differences in temperature or density (i.e. moisture content), or by wind or stack effect. Convective heat loss is proportional to the differential in temperature between object and air, the quantity of moisture present, and the speed of air movement. Therefore, failure to control air movement (and moisture) in walls and within SWI presents risks of significant performance loss. Where SWI system boundaries are not sealed (e.g. base rail or verge trim) -- and particularly where wall surfaces are irregular -- pressure differentials may move significant quantities of air between system layers.

Another route of thermal loss is convective transfer (thermal bypass). This occurs when warm air moves within a cavity (in the absence of other forces, this is triggered by its lower density), before cooling and then falling (due to higher density). Voids within system layers present likely sites for thermal bypass. Significant voids are likely where pebbledashed walls have not been parge coated, or where hips (i.e. flares) or surface variations have not been levelled prior to installation. Energy performance gaps correlated to voids behind insulation which are larger than assumed values have been shown to be significant (Zero Carbon Hub 2014, p.28).

Radiation

Radiative loss is present any time an object has a higher temperature than the surfaces that surround it. Radiant transfer is interrupted by any object inserted into a field of radiative transfer.

Radiative transfer in SWI is primarily a function of emissivity of surfaces within the SWI system and at inner and outer faces of the wall. Failure to make specifications such as providing insulation with low-radiative facing of smooth render finishes may neglect the opportunity to reduce radiative transfer. In IWI, an opportunity exists to install material behind reinstated heating exchangers to reduce radiative loss.

2.5.2.2 Thermal mass and configuration of insulation

Thermal mass significantly reduces diurnal temperature swings when coupled to indoor air. The benefit of isolating or coupling conditioned spaces to thermal mass may be lost during SWI retrofit.

The effect on performance of placing insulation to the inside or outside or a wall (or middle) has been examined by a number of authors. Kossecka and Kosny (2002) used data from six US climates and concluded that optimum thermal performance was obtained in all conditions when massive materials were directly exposed to interior space. Al-Homoud (2005) argued that winter passive solar heating and summer convective cooling are facilitated by positioning insulation to the exterior of thermal mass. Using UK climate data, Bojić and Loveday (1997), determined that with intermittent heating, 'insulation/masonry/insulation' configuration saved 32 per cent more energy than the opposite configuration. The inverse effect was found for intermittent cooling, showing reduced thermal lag of insulated inner surfaces. Al-Sanea and Zedan (2011) and Ozel and Phitili (2007) determined time lag and decrement factor were optimal in a configuration of three equal insulation pieces placed at the internal, middle, and external of the wall. Ozel and Phitili (2007) (using Turkey climate data with various wall orientations) found the worst performance correlated to IWI configuration, while the best correlated to middle or EWI configuration.

The utility of coupled thermal mass will vary in different areas within a home and ideal heating and cooling responsiveness and decrement will largely be determined by occupancy pattern and behaviour. CIBSE (2005) showed with modelling and case studies that significant improvements of thermal comfort in living rooms were typically linked to higher thermal mass. In bedrooms, however, lower mass houses enabled the benefit of responding quickly to cool night air.

Research suggests that EWI may have better performance for typical occupancy patterns than IWI in terms of responsiveness and decrement. IWI reduces response time, but may also increase diurnal temperature variation. It is correlated to lower radiative cooling and retention of internal gains (Energy Saving Trust 2010; Porritt et al. 2012). These effects can be partially negated by maximising exposed thermal mass (e.g. concrete, stone, or clay floors) in conjunction with IWI (English Heritage 2011), specifying dense materials (e.g. plastered internal walls), or employing cross ventilation and night time purging (Energy Saving Trust 2010b; Hacker et al. 2005; Gupta & Gregg 2012; Orme et al. 2003). A similar benefit might be provided by installation of phase change materials.

This research calls for consideration of occupancy and coupled thermal mass in specification of SWI and ventilation.

Overheating and a changing climate

Overheating -- particularly during summer -- is an important potential unintended consequence of SWI. This risk is exacerbated by IWI, and is correlated to shading and surface albedo, ventilation and air tightness, occupancy, weather and building typology.

Beizaee, et al. (2013) present one of the first national scale studies of summertime temperatures in English dwellings. They find that solid stone walls coupled to indoor spaces (i.e. not IWI) were associated with cooler indoor summer temperatures. Francesca, et al. (2013) examined the performances of three traditional wall constructions (1940's to 1980's) and concluded that higher levels of insulation combined with high thermal mass may lead to overheating; they suggested this might be resolved by ventilated EWI systems. Al-Sanea and Zedan (2011) studied dynamic thermal characteristics of SWI insulated walls using Riyadh climate data and showed that differences in insulation thickness and distribution were correlated to a 100 per cent variation in heating time lag and a 20 per cent difference in peak cooling and heating transmission loads.

Porritt, et al. (2012), modelled IWI and EWI to investigate the effect of shading, insulation, and ventilation strategies in UK dwellings comparing weather data from the 2003 heat wave to monitored data. Interventions which reduced solar gains (including EWI) were shown to be effective at limiting heat gain. This quality is also reported by many other authors (Gupta & Gregg 2012; Oikonomou et al. 2012; Energy

Saving Trust 2010b), who recommend finishing external surfaces with high albedo finishes to reduce solar heat gain.

SWI relies partially on control of heat gains through air tightness (inflow) and ventilation (outflow) in order to control overheating (Energy Saving Trust 2010b; CIBSE 2005). This suggests that SWI retrofit should be accompanied by relevant assessment and provision of ventilation.

There is ample evidence to suggest that even employing aggressive controls for overheating, many buildings in future are likely to overheat. For instance, Kershaw and Coley (2009) studied the response function of a large number of buildings in relation to predictions of future climate. Results showed that with more aggressive climate change scenarios, increasing numbers of buildings would experience up to 90 per cent of occupied summer hours above 28°C by 2080.

During periods of abnormally high summer temperatures in the UK, evidence indicates a positive effect on levels of mortality (Hajat et al. 2002) and (for certain groups) hospital admissions (Johnson et al. 2005).

The importance of controlling indoor temperatures during heatwaves is underscored by modelling by the Hadley Centre which predicts that by the 2040's, a 2003-type summer is likely to be roughly average (Stott 2004, as cited by Kershaw & Coley 2009).

Additional research has examined localised compounded overheating risk in UK dwellings associated with Urban Heat Island Effect (UHI) (Oikonomou et al. 2012; Mavrogianni et al. 2012). This factor is important to account for in SWI specification.

This work points to a clear need to consider future climate scenarios during SWI specification. At present, there is no SWI system on the market that would allow for easy removal of insulation should a shift in climate lead to overheating. Therefore, provision of appropriate shading and surface albedo, ventilation and air tightness, as well as careful consideration of occupancy, weather and building typology are important strategies to consider in order to minimise unintended increases in heating or cooling energy demand under future scenarios.

2.5.2.3 Moisture

Moisture pathways in building fabric

Uncontrolled diffusion, precipitation ingress, and rising damp are potentially detrimental to insulation performance, fabric integrity and IAQ. Moisture ingress may occur via many routes, such as failed rendering, seals around windows, or leaking roofing or rainwater goods. Internal sources of moisture include metabolic gains, bathing and cooking, leaks in wet areas, pipes or ducting.

Post-1919 UK housing typically employs a simple exclusion principle of limiting moisture ingress into exterior walls by use of rendering or cementitious masonry. Where imperfect installation has occurred, or maintenance has been inadequate, fissures and cracks may allow direct ingress or moisture diffusion into the wall. This is particularly problematic if IWI has reduced the wall temperature or moisture becomes trapped in EWI.

Precipitation ingress typically occurs at distinct times and locations and is a common result of poor installation or maintenance of barriers. If adequate means of drying to the exterior or interior are unavailable -- for instance by the installation of low-permeance SWI materials -- then a critical problem may develop.

In EWI, the primary source of moisture damage has been shown to be precipitation around windows and joints by Künzel & Zirkelbach (2008). The authors studied temperature and moisture distributions in EWl assemblies on lightweight structures and report modelling which suggests that assemblies fail with just 1 per cent penetration of wind-driven rain (WDR).

Quantification of WDR began with research by R.E. Lacy in 1951. Unlike other forms of preciptiation which wet only horizontal and sloped surfaces, WDR wets vertical surfaces and can be a significant source of wetting. British Standard BS 8104 provides guidance for assessing exposure of walls to WDR (British Standards Institution, 2008). Hens (2010) argues that measuring and predicting WDR is complex and computational fluid dynamics (CFD) is not yet capable of adequate predictive accuracy.[19]

Air movement is caused by differentials in temperature, vapour pressure, air pressure (wind or stack effect), and mechanical ventilation. When uncontrolled, this may cause significant moisture transport between interior and exterior spaces, and between interstitial areas of building fabric.

Diffusion will occur via the course of least resistance, for instance through unsealed cracks in the building envelope. Under normal conditions, moisture diffuses through building fabric slowly. Diffusion driven by seasonal differences in indoor and outdoor conditions can be significant.

Because warmer air is capable of holding more vapour than cooler air, as air temperature falls, capacity to hold moisture diminishes. Hence, a fixed unit of air with fixed moisture content will have a rising relative humidity measurement as

[19] Hens (2010) argues that several aspects of WDR behavior are well understood: events that occur when a drop of rain hits a surface, how walls should be constructed in order to be rain-tight, and the effects of rain absorption on wall's thermal properties. He argues, however, that run-off is highly complex and cannot yet be addressed by models and he draws several important conclusions which are useful in the design of buildings to resist WDR.

temperature falls. Ultimately, as air cools below dew point, moisture precipitates – or if air meets a surface below dew point, then moisture will condense on that surface.[20] De Freitas, et al. (1996) demonstrate significant wetting of walls due solely to interstitial condensation. Condensation risk -- particularly in interstitial spaces -- is hugely important to account for in SWI specification. Condensation can lead to significant moisture accumulation, particularly without frequent drying-out periods.

Stirling (2002a) addresses condensation risk in vapour permeable IWI and 'reverse condensation'. He highlights the greatest risk is on walls facing ESE and WSW.

BRE (2007) notes that without a damp proof course (DPC), the porous structure of stone, bricks, blocks and mortar enables rising damp to create a column of water "far higher" than one metre.

An uncommon, but potentially more robust design for EWI is the rainscreen or 'drained cavity' system, which contains a small cavity so that any water that might penetrate the exterior surface is controlled. This may be a promising area for future research of controlling moisture in EWI.

There is clear evidence that ingress, convection, diffusion and capillary action can contribute to elevated levels of moisture in walls, and that this is aggravated by low drying potential of externally or internally clad walls. SWI specification must ensure appropriate mechanisms of moisture control, and correct specification, installation and maintenance are essential.

Closed cell and open cell materials

A fundamental division between insulation materials is made between open cell and closed cell structure. Open cell materials (also called 'vapour permeable' or 'breathable') have the capacity to allow water in liquid or vapour form to pass through the material. Mineral wool, glass wool, or sheep wool insulation are all examples of open cell materials. Open cell materials present advantages and disadvantages: while they will not trap moisture, they have capacity to absorb it and thus increase thermal conductivity.

Closed cell materials (also called 'vapour impermeable' or 'non-breathable') are, with very few exceptions, foams produced by the introduction of blowing agents to a polymer. They typically have lower lambda values.[21] They offer neither the potential

[20] Vapour pressure, which is a function of the quantity of water vapour in a volume of air, varies according to air temperature. Relative humidity is a measure of percentage saturation, calculated in relation to saturated vapour density. That is, it is the amount of vapour held in air at a given temperature, relative to its total capacity. The dew point temperature, then, is the temperature at which water vapour changes phase into liquid state.

[21] Closed cell insulants generally have denser structures than open cell insulants, and the matrices formed by blowing agents are typically very thin (thus limiting conduction). The gas

advantage of allowing moisture to ‘escape’ from building fabric, nor the disadvantage of allowing moisture accumulation behind insulation (assuming the installation’s occlusion is perfect).

Some materials – most notably EPS – resist neat categorisation. EPS is an example of a closed cell structure which, with extensive pockets of air interlaced around beads of closed-cell material, may exhibit behaviour similar to some open-cell materials.

Some products may be faced with a vapour barrier or vapour retarder, which may or may not also include a radiative barrier. Such products rely on the installer to seal the insulation to abutting insulation and elements (e.g. with foil tape) to form an integral barrier.

Appropriate specification and installation practices must balance the permeability of insulation materials with moisture exclusion and occlusion in the existing fabric and vulnerability of building components to moisture.

Vapour accumulation and the ‘breathability debate’

An ongoing debate surrounds the topic of ‘breathability’ in insulated walls. One argument asserts that impermeable materials are potentially ‘dangerous’ for use in buildings because of their propensity to cause moisture accumulation, and are particularly inappropriate for use in traditional constructions. The countering argument claims that these risks are overstated and that a variety of mechanisms will mitigate actual risks in the vast majority of cases.

Kingspan Insulation (2009) rejects claims made about the importance of breathable construction and insulation, and argues that ventilation in buildings plays a very important role and acknowledges that if air-borne moisture in a building is allowed to remain, it may lead to condensation and related problems. It argues that 95-96.7 per cent of vapour transfer from a house with ‘breathable walls’ occurs through ventilation not diffusion, and that bulk air exchange is at least 19 times more important in controlling moisture problems than ‘breathability’. It states that vapour diffusion does not contribute significantly to the rate of vapour transfer from a house and calls breathability a “red herring”.

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used as a blowing agent often has a lower thermal conductivity than air and in closed cell foams it remains trapped in the polymer when the foam sets, the material retains a low U-value. Over time, however, these foam insulants tend to ‘off-gas’ or lose a proportion of the blowing agent, thus resulting in a rising U-value (this is exacerbated by the comparatively rigid structure of these foams as compared to open cell foams, which makes their integrity more prone to building movement). This process may be accelerated in some insulants by the presence of water in liquid or vapour state, thus leading to increased energy loss through both conduction and convective loss. Hence, as the exterior face of the material becomes warmer, radiative loss too will increase.

May (2009) argues against many of Kingspan Insulation's (2009) points and notes that 'breathability' was established by the historic building sector to describe not just vapour permeability but also hygroscopicity and capillarity. He reports modelling of EWI on masonry in which constructions generally have few problems with moisture until higher levels of rainfall are simulated. He adds that porous wood fibre insulation systems do not accumulate moisture in this modelling while PU and EPS systems do. May argues for the importance of the qualities of 'natural' insulation materials.[22] He asserts that most 'non-breathable' systems are modelled based on homogenous sections without inclusion of wall or floor junctions and argues these junctions are highly vulnerable to vapour entry. He points to the importance of hygroscopic buffering in controlling humidity in buildings.

Clearly, where moisture control relies on preventing vapour from diffusing into an SWI makeup, it is vital that this is actually achieved. Pavlík and Černý (2008) use laboratory techniques to simulate on-site conditions and assess hygrothermal performance of building envelopes. They apply an IWI mineral wool system to two common structure types exposed to a range of climate conditions. Results demonstrate satisfactory hygrothermal behaviours where vapour diffusion resistance is adequately specified. Toman, et al. (2009) assess in-situ hygric and thermal performance of a mineral wool IWI system without a vapour barrier (but with lime-cement between IWI and wall) sited in a late 19th Century brick building in Czech Republic. The authors note a 'very good' level of hygrothermal performance with no condensation observed over a four year period. Moisture transmittance of wall elements is affected by the hydraulic properties of all component materials and not just the insulation. For instance, gypsum plaster may play an important role in hygrothermal behaviour (Wang 2011). Where VCLs may present a risk of 'reverse condensation', a vented airspace is recommended on the cold side of insulation; alternatively, low vapour resistance external surfaces may be specified.

Other research underscores the risk of loss of thermal performance in highly permeable insulation materials without adequate drying mechanisms. Karamanos, et al. (2008), investigate stone wool insulation under varying temperature and humidity conditions using modelling and long-term laboratory experiments. They show significant increase in thermal conductivity due to vapour condensation in the insulation, nearly to values expected of masonry materials (practically of no insulation value). The authors argue that although humidity will inevitably penetrate most stone wool installations, this does not pose a significant problem as long as the

[22] May founded and at the time of his publication was the chief executive of Natural Building Technologies, a retailer of many 'natural' insulation products. He is currently an Honorary Research Fellow at The Bartlett, UCL.

construction enables sufficient aspiration to allow drying. The authors suggest that the 'real point of danger' is using highly vapour resistant outer layers in constructions such as some paints and plasters which might trap moisture. Künzel, et al. (2006) found that EPS EWI on North American lightweight constructions cannot provide significant drying toward the exterior and may pose a risk of moisture damage to the building fabric. The author recommends an interior VCL specified to allow vapour diffusion toward the inside. He notes that replacement of EPS with high density mineral wool slabs or provision of drainage behind insulation might be advisable.

The ongoing debate about the risk of vapour accumulation in SWI points to immaturity in research. Much of the literature on moisture risk and SWI draws on non-UK weather data or addresses lightweight constructions. Certainly in the UK context, literature shows little consensus about the appropriateness of specification and installation practices. No meaningful post-installation investigation of successes or failures of moisture management in SWI has contributed to this debate.

Predictive assessment of moisture

Simple manual or graphical assessment of dew point temperatures based on steady-state conditions can be applied to notional wall sections.[23] Early computer modelling offered improvements in calculation power, but did not accurately capture moisture behaviour -- particularly in heterogeneous walls. Karagiozis (1998), for instance presents relatively early modelling prediction using a transient 2-D and 3-D model to investigate heat, air and moisture transport through various EWI systems.

Complexities emerge when three-dimensional hygrothermal dynamics are considered, when variations in indoor and outdoor climates are accounted for, and when fabric details are examined more closely.

Computer modelling programmes such as WUFI® or MOIST are capable of dynamic 3-D analyses of moisture and energy flows over time against variable weather data. Despite vast advantages in computational power when compared to manual assessment, the accuracy of these models remains limited.

BS 5250 (British Standards Institution 2011) outlines procedures for the calculation and prediction of condensation and high interstitial humidity. The methodology does not account for 3-D hygrothermal dynamics which are particularly relevant to predicting moisture behaviour in SWI. Still, it presents a wide variety of principles of successful control of condensation, which includes discussion of IWI and EWI. It demonstrates that while both pose condensation risks, IWI clearly poses higher risks.

[23] Manual assessment of dew point temperatures can be made with psychrometric chart, Glaser or Kieper diagram.

To reduce risk, it recommends that thermal bridges should be minimised and temperature gradients maximised by detailing such as returning insulation into reveals and along abutting internal walls. Where their use is deemed appropriate, intact and unbridged VCLs should be returned into reveals. BS EN 15026 (British Standards Institution 2007) offers an alternative standard which is increasingly favoured by building scientists for use in SWI specification. The standard is based on a dynamic model which includes hourly changes in temperature, relative humidity and surface wetting (including element orientation).

Predictive assessment of hygrothermal behaviour allows an understanding of moisture pathways in buildings and so the development of strategies for moisture management. In practice, characteristics of building materials, local climate, and internal conditions are often assessed informally, and rules of thumb may be the dominant form of risk mitigation. Despite arguments in the research community, numerous guides for managing condensation risk in construction work have been available to builders for many years (e.g. BRE 1992).

Risks associated with moisture in buildings

Moisture and biological growth

The risks of biological growth include consequences for the integrity of building components as well as IAQ and human health. Excessive moisture in building materials will generally lead to proliferation of moulds, mildews, and other decay fungi when adequate warmth, organic substrate, and reproductive spores are present. Typically, these organisms require relative humidity in excess of 80 per cent.[24] Reproductive spores are pervasive and are likely to be transported by air to all areas of a building; if conditions are suitable, biological growth will ensue. These organisms present hazards to human health and the integrity of the substrate (i.e. building material) on which they feed (Brandt et al. 2012). If interstitial spaces in building fabric accumulate adequate levels of moisture, they are already likely to provide the warmth and organic matter requisite for fungal growth. Similar risks are presented of infestation of insects, mites and other Arachnida, or propagation of harmful bacteria.

Brandt, et al. (2012) analysed a range of IWI cases over roughly two decades for mould growth risk. They find that IWI may cause low temperatures and high relative

[24] Evidence from analysis of Warm Front refurbishments (Oreszczyn et al. 2006b) suggests that if damp autumn periods are accounted for in analysis, mould growth increases above standardised relative humidity of 45 per cent. The authors of this research suggest that this may be particularly important to micro-climates including surfaces at thermal bridges.

humidity on the interior face of a wall, which is likely to lead to mould growth. They argue that risk of mould can be minimised if:

- the wall is not made of highly absorbent bricks or leaking mortar joints;
- the interior surface of the wall is free from organic materials (e.g. wallpaper or glue);
- the vapour barrier is airtight; and
- an inorganic insulation with high capillary action is employed (as this will facilitate equilibrium of vapour pressure and so reduce diffusion) – however, the authors note that thermal performance may vary due to periodic critical moisture content.

It is important that SWI does not exacerbate the risk of biological growth. Although the complexity of factors makes prediction difficult (Viitanen, et al., 2010), there is a robust literature on the assessment of conditions necessary for growth (Sedlbauer 2002b).[25]

Impacts of damp in buildings on human health

Poor specification, installation or maintenance of SWI may lead to elevated moisture and relative humidity.

The impacts of damp and poor IAQ on occupant health and well-being are well documented (Roys, et al. 2010; Davidson, et al. 2011; Davidson et al. 2012). Research in this area is quite mature; public health and housing professionals in the early 20th Century were aware of the associations between housing conditions and poor health, increased infant mortality, and infectious disease. A multitude of studies since then have investigated correlations between damp and ill health (Hynes et al. 2003), including the effects of indoor mould growth on adult asthma (Zock, et al. 2002) and on asthma, allergic rhinitis, atopic dermatitis, incidence of common colds and other respiratory infections (Kilpeläinen, et al. 2001). Emenius, et al., (2004) showed an association between living in homes with high humidity and increased instances of wheezing. Koskinen, et al. (1999) found significant association between exposure to mould and sinusitis, acute bronchitis, nocturnal cough, nocturnal dyspnoea and sore throat. They also observed significantly more episodes

[25] Mould risk was once predicted based solely on temperature ratios in buildings. More sophisticated methods which account for surface temperature and relative humidity are now used (e.g. isopleth systems, biohygrothermal model, ESP-r mould prediction model, empirical VTT model) (Vereecken and Roels, 2012). Sedlbauer (2002a) developed a biohygrothermal model which he asserts far exceeds previous predictive methods.

Hyvarinen, et al. (2002) associate a range of fungal genera and actinobacteria with specific types of moisture-damaged building materials. They found that concentrations of fungi and bacterial numbers were generally highest on materials such as wood and paper products, and lowest on products which included mineral insulation and ceramic products.

of common cold and tonsillitis, cough without phlegm, nocturnal cough, sore throat, rhinitis, fatigue and difficulties in concentration.

Bone, et al. (2010) summarise the impact of energy efficiency interventions on occupant health and assert that many health hazards are linked to insufficient ventilation. They call for further research to investigate relationships between energy efficiency measures and occupant health.

Prolonged drying and risks to building fabric

Prolonged exposure to moisture due to inadequate drying potential presents risks to building fabric which include corrosion, rot, destructive biological growth and freeze-thaw damage.

Wood is at particular risk in IWI due to potential exposure to prolonged damp or wet conditions. Hygrothermal modelling by Morelli, et al. (2010) finds increased condensation risk at beam ends in IWI under WDR conditions. The authors caution this unintended consequence results from reduced drying potential. Their work underscores the importance of informing specification of moisture control mechanisms with careful assessment of moisture risk.

Strauße (2009) investigates the risks of freeze-thaw damage, corrosion of embedded steel components, mould growth and deterioration risks associated with IWI in cold climates. He employed measurement, monitoring and WUFI® simulation and found a low risk of freeze-thaw damage correlated to IWI, but an increased risk of steel corrosion under severe conditions. Recommendations include control of excessive wetting of walls through maintenance of pointing and effective detailing, and the inspection of embedded steel prior to IWI installation.

Stud and mineral wool IWI systems are found to present a high risk of wintertime condensation and mould growth in walls by Brandt, et al. (2012). This is supported by simulations run by authors of a recent report by the US DOE (Strauße et al. 2012) which suggest concern for embedded timber due to hygrothermal conditions within walls. This work suggests that in-situ measurements should be made to verify temperature and moisture conditions before undertaking IWI.

Risks of prolonged drying are particularly obvious in IWI, and so research of the topic in SWI contexts is skewed toward IWI. The risk of moisture becoming trapped by poor practices in EWI points to a need for more research of the risks of damage to building fabric.

2.5.3 Further risks and unintended consequences

2.5.3.1 Waste

Production of waste in SWI varies considerably, and particularly in relation to pre-installation phases. For instance, EWI might entail the removal of existing rendering, roofline alterations, replacement of windows and doors or linings and trim. IWI could include replacement of drylining, radiators and services, skirtings, coving, architraves, window and door lining and trim, or furnishings and fittings (e. g. kitchens and baths).

In general, SWI is likely to produce less packaging waste than general refurbishment projects are, which has been shown to account for as much as 50 per cent of waste leaving general sites (Anderson et al. 2002). BRE has published widely on waste issues (BRE Centre for Resource Management 2003; Hobbs & Kay 2000; Moulinier et al. 2005; Hobbs et al. 2005). Limited numbers of pre-refurbishment and pre-demolition audits, however, have been carried out on SWI works (Hobbs 2012).

Resource efficiency is not a focus in today's SWI management practices. Improving benchmark indicators for waste in SWI -- which currently relate only to project value and floor area (Hobbs 2012) -- is an important area of future research.

Management of waste on site to prevent local pollution is as important in SWI as in any other form of construction. This includes protection of waterways from dumped liquids and containment of debris and harmful dusts.

Finally, management of waste streams, recycling, and end-of-life recovery are important, but largely unaddressed, topics relevant to SWI.

2.5.3.2 Historical and traditional buildings

Many authors argue that the differences between thermal and moisture behaviours of materials and constructions found in modern and traditional buildings have important implications for performance and for risk to building fabric (Jenkins 2008; Urquhart 2007; English Heritage 2011).

Adding to the complexity of refurbishing older constructions is the need to consider historic value and period features in many properties. SWI may alter the general character of buildings due to overcladding -- losing original finishes (e.g. plaster, paint, panelling, mouldings) and affecting dimensional changes. The discourse surrounding heritage value and the need for sensitivity in SWI -- while hugely important -- is largely outside the scope of this research.

More germane is the ability of practitioners to deliver SWI without causing harm to building fabric or presenting health hazards. Yet the substantial debate about physical risks to traditional buildings cannot be answered by simply leaving buildings uninsulated. Pre-1919 buildings comprise a considerable proportion of national stock (Section 2.1) and SWI in these buildings is a fundamental component of the strategy to meet energy targets for the built environment.

The debate about maintaining airtightness versus 'breathability' of buildings introduced in Section 2.5.2.3 is of central importance to the treatment of historical and traditional constructions. Numerous authors have contributed to this debate.

English Heritage (2008) asserts that the main risks to heritage buildings are: moisture trapped within materials, condensation within unheated areas of the building, condensation at thermal bridges, and insufficient ventilation and heating to remove moisture. It recommends adequate ventilation, use of hygroscopic building materials, and minimisation of barriers to moisture flow in building elements. It argues that natural fibre-based materials are suitable for meeting these recommendations, while conventional materials (e.g. fibreglass and mineral wool) tend to retain moisture and increase risk of damp problems. Finally, it encourages care to avoid blocking existing natural ventilation routes (e.g. eaves or airbricks).

The Institute of Historic Building Conservation (2007, p.2) argues, "Modernisation techniques based on air-tightness and ill-considered positioning of vapour barriers are often incompatible with property built traditionally in which the ability of the fabric to move and breathe is vital for its long-term safety and future". This is echoed by Urquhart (2007). A countering argument highlighting the importance of airtightness for energy conservation and prevention of condensation is made by other authors (Sanders 2006).

May and Rye (2012) call attention to the risks of refurbishments which reduce permeability of building fabric, or which impede 'breathing' performance. The authors highlight what they argue is a lack of quality research and guidance for energy refurbishment of traditional buildings. They assert that methods of assessing heat loss in traditional buildings often underestimate performance, and that tools for assessing moisture risk are inadequate. Other authors argue that notional u-values of vapour permeable constructions tend to over-estimate actual heat loss and so the assessment of the necessary insulating in historic stock is itself overestimated (English Heritage 2011; May 2012).

Another debate surrounds the appropriateness of IWI versus EWI in traditional buildings. EWI is generally regarded as presenting fewer risks than IWI. Urquhart (2007) provides a comprehensive guide to considerations for alterations to historic buildings. Authors in this debate tend to focus on the risks and drawbacks associated with IWI in traditional constructions, which include (Urquhart 2007; English Heritage 2011):

- reduction of temperature in the wall (freeze-thaw damage, degradation);
- movement of dew point (and risks if this falls at the intersection of organic materials or absorptive materials);
- potential damage to walls from trapped moisture (including wall ties), damaged VCLs, or airtightness measures;
- dimensional change near shutters, windows, and doors and potential operational impacts or reduced ventilation;
- condensation risk due to reduced thickness of insulation around fenestration and abutting elements; and
- reduced exposed thermal mass leading to poor moderation of indoor temperature (affecting integrity of fabric and building contents).

Most authors agree that further research is urgently needed to answer these questions. May and Rye (2012) present a knowledge gap analysis on the topic of retrofitting traditional buildings in which 512 documents and 1241 references were mapped. They argue that in nearly every category of knowledge there are 'major knowledge gaps'. They report a lack of data regarding traditional materials and construction and suggest an over-reliance on modelling. They argue that current conventions for thermal analysis (BR 443 including RdSAP) and moisture analysis (BS 5250) are ill-suited for traditional buildings. May (2012) points to three main gaps in research: performance of the housing stock, whole house performance, and retrofitted performance of solid walls. He asserts that many areas of importance (e.g. overheating, occupant interaction, user health, energy conservation and building conservation) have 'almost no research or guidance' and highlights significant gaps in data about SWI and material behaviour, weather patterns, moisture behaviour, durability of fabric over time, and construction fault modelling. These arguments run parallel to the report produced by May and Rye (2012).

It is clear that buildings which once relied on uncontrolled infiltration and breathable fabric elements to control moisture must be approached carefully in SWI projects. The installation of low permeability SWI systems -- particularly in concert with modern heating systems (which reduce air movement compared to open fires), indoor plumbing, and even air conditioning –- may present significant risks.

Research in this area underscores the importance of caution and analytical rigour when specifying and installing SWI in traditional buildings.

2.5.3.3 Mechanical failure

Guarantees against mechanical failure -- most commonly based on standards endorsed by the British Board of Agrément (BBA) -- require adherence to set specifications for each step of installation.

Logic suggests that failure to match installation practice to these specifications may risk mechanical failure. This consideration is standard to a great deal of construction work, and in SWI likely vulnerabilities include: inappropriate storage conditions of adhesive, renders or insulants, improper surface preparation, incorrect fixing techniques, failure to properly install or maintain sealants or occlusion layers, or failure of the wall substrate.

Poor practice may result in delamination of render or adhesive layers, flexing of the insulation board or trim materials, ingress of moisture due to movement in joints or components, or in extreme cases materials falling off of the wall.

No published research was found documenting the risks of mechanical failure in actual SWI installations.

2.5.4 Best practices, best practice guidance and industry standards

2.5.4.1 Overview of best practice guidance

The potential unintended consequences of poor specification or installation practice have been shown to be diverse. Guidance to the specifier or installer is largely comprised of specifications provided by manufacturers and system suppliers and communicated through short training courses (i.e. 'carding'). These specifications are endorsed (e.g. by BBA) and accepted by product guarantors.

An abundance of best practice guidance exists in grey literature dating from the 1970's, although it typically contains broad and general recommendations and lacks recommendations for detailing and discussion of challenges with specific insulation systems or building types (BRE 2006; Energy Saving Trust 2008; Stirling 2001; Stirling 2002a; Honour 2010).

By the 1990's, guidance documents began to reflect a recognition of many of the risks of poor SWI practice (BRE 2000; BRE 1996; Mason 1992; BRE 1989). Stirling (1999) provides a general overview of EWI systems, and highlights areas of concern such as ageing joint sealants, sufficient overhangs at the roof/wall interfaces, and higher thermal movement resulting from darker finishing colours. General guidance on selection, cost, detailing, maintenance and durability is provided by many authors (Energy Saving Trust 2008; Stirling 2001; Stirling 2002a; Stirling 2002b; Energy Saving Trust 2006a; Energy Saving Trust 2006b; Strauße et al. 2012).

Other examples of relevant general building best practice guidance documents can be found (BRE 2006; Jaggs & Scivyer 2006). These documents present advice on minimising air leakage and thermal bridging and highlight correlations to condensation, mould growth and energy loss. Discussion of thermal bridging appears in Baker and BRE (2013); this can be usefully applied to SWI installation and design. Harrison and de Vekey (1998) provide a comprehensive guidance document on general avoidance of defects in construction. It does not discuss SWI at a substantive level, but presents many relevant principles of practice such as the importance of rectifying building defects, controlling air leakage and detailing for moisture control. Doran, et al. (2009) describe earlier forms of construction and problems likely to be encountered, while providing solutions and discussion it provides a comprehensive guide to issues such as condensation control, damp, and maintenance.

Other sources available to industry address implications of refurbishment practices (e.g. King & Weeks 2010) and provide case studies (Ferguson 2011; Energy Saving Trust 2011a; Energy Saving Trust 2011b; Yates 2006; National Refurbishment Centre 2012).

2.5.4.2 Moisture detailing

Detailing and design to control the ingress of moisture into buildings and in general building work is a mature area of research and is described in many pamphlets and grey literature sources (Property Care Association n.d.; Thomas et al. 1992). Many highlight the risks of sealant failure, inflexible sealants (e.g. cement mortar), leaking water supplies, or cracked modern renders.

Moisture is addressed in the majority of guidance documents, including those already introduced. Some documents address moisture specifically; Honour (2010) offers focussed recommendations such as ensuring that service penetration points and joints be well-sealed, and insulation is returned along reveals and internal partitions. Stirling (2002a) recommends using high vapour resistance plasterboard laminates to minimise risks with IWI against masonry, spacers behind battens used to fix IWI, and description of ventilated cavities. King and Weeks (2010) urge that careful attention to detailing is made (e.g. holes made by fixings in EWI) in order to ensure durability of systems.

There is a growing body of literature on moisture and SWI but significant debate remains, particularly in the UK context. This builds on the expansive literature on moisture behaviour in buildings and materials (Section 2.5.2.3).

Trotman, et al. (2004) is a substantial general resource on protection against and effects of damp in existing buildings. It points to many risks of damp and SWI, suggesting that while the extents of problems such as 'reverse condensation' are unknown, they are likely common. It suggests that inadequately designed or maintained water-tightness features are commonly found in UK housing. The book offers many suggestions for IWI and EWI systems.

Recommendations in academic literature offer details which are generally absent in industry guidance. Large reports by government bodies offer similar detailed guidance, but like academic literature are unlikely to be consulted by practitioners. The US DOE (Strauße, et al., 2012), for instance, offers recommendations for controlling risks in IWI including balancing the benefits of increasing thermal resistivity through added insulation against the risk of freeze-thaw damage, minimising air leakage to reduce interstitial condensation risk, while managing risk to IAQ through “mechanical ventilation, pollution source control, and combustion safety measures” (Strauße et al. 2012). The US DOE in Baker (2013) presents research on EWI of masonry and wood-framed walls which highlights the need for improved water management around windows, doors, decks, and roof-wall intersections. Baker (2013) offers a range of solutions for attaching thick layers of EWI, but suggests further guidance about water detailing is needed, and points to inadequate understanding of deflection in EWI (particularly of heavier claddings in exposed environments).

2.5.4.3 Rain exposure

Most guidance on managing high exposure to WDR in IWI systems recommend a small cavity behind dry lining and urge maintenance of mortar joints (Energy Saving Trust, 2006). Honour (2010) suggests that EWI ought to include a ventilated cavity, and that IWI must fit tightly and plasterboard should be sealed fully along all edges and penetrations to prevent moisture problems.

Stirling (2002a) recommends applying ‘breathable’ external finishes in SWI and cautions that rendered SWI should not be specified for Exposure Zones above 4. In areas with high exposure, closed cell or encapsulated insulation is advised to reduce risk of moisture retention. Robust moisture controls are recommended for walls in Zone 3.

2.5.4.4 Damp walls

Existing damp walls are difficult to accommodate and recommendation is made that walls are allowed to dry prior to SWI work. Energy SavingTrust (2006) suggest that internal studwork should be used for IWI systems in these circumstances (and timber treated with preservative). External pointing or rendering to reduce damp penetration is recommended. It also recommends that weather conditions are suitable at time of wet render application.

2.5.4.5 Thermal bridging

Ward (2006) provides guidance on assessment of thermal bridges at junctions and openings and their impact on heat transfer; as well as numerical modelling and assessment of the prediction of risk of surface and interstitial condensation. Defra (2002) provides useful guidance on detailing for reduction of thermal bridging as well as air leakage. Thermal bridging and penetrations become nearly unavoidable in IWI systems, however guidance describes how to minimise their occurrence (Al-Homoud 2005).

Stirling (2002b) provides considerable guidance for reducing thermal bridges, including treatment of junctions with cold roofs to ensure unimpeded roof ventilation. Other guidance offers recommendation for treating door and window reveals, including Energy Saving Trust (2006) which suggests that insulation with an R-value of $0.50m^2K/W$ should be specified to reduce the impact of thermal bridging. Existing window frames may make this impossible to achieve with conventional materials, which would require too great a thickness of insulation; high performance materials (e.g. aerogel) could generally achieve this value within the available space.

2.5.4.6 Substrate

Energy Saving Trust (2006a) cautions that EWI is not suitable if the existing substrate is structurally unsound or cannot be repaired and fixings should be made only following verification of substrate condition, consideration of loads, and potential for corrosion and movement. Appropriate renders should be selected and where necessary movement joints provided and movement of metal components within render considered. The author suggests that manufacturers are consulted to ensure that the correct adhesive is used. BS 5628: Part 3 (British Standards Institution 2005) provides a useful guide to determining suitability of wall substrate for IWI.

2.5.4.7 Thicknesses

Topics of accommodating the thickness of insulation, including at window and door reveals, against neighbouring properties, under eaves, and potential heritage concerns are highlighted by Honour (2010) and Energy SavingTrust (2006).

Attention to detail is recommended around window cills, rainwater goods, and areas where walls meet roofs and projections such as porches or conservatories, and care is recommended to avoid blocking window trickle vents or eave ventilation by several authors (Energy Saving Trust 2006a; Stirling 2002a).

2.5.4.8 Traditional constructions

Many of the documents presented in Section 2.5.3.2 contain best practice guidance for SWI in traditional constructions. English Heritage presents guidance (English Heritage 2011) for handling potential conflicts between Part L requirements and the conservation of traditional buildings. It encourages careful study before carrying out alterations. The report also outlines four categories of heritage value which should be considered: evidential; historical; aesthetic; and communal value. Retrofit design recommendations include repairs which do not preclude later repairs; “reversibility”; “compatibility”; “authenticity”, and breathability.

2.5.4.9 Hard-to-treat cavity

Guidance on risks, materials, methods, and principles for improving energy performance of early (pre-WWII) cavity walls is widely available. Many early cavity buildings were built with lime-based mortars and renders; Ogley (2010) argues that any insulation installed should maintain this ‘breathability’. He points to disadvantages (or potential disadvantages) of EWI including reduced solar drying. IWI, which reduces the heat passing into walls, can cause cavity temperature to fall considerably. Ogley cites research which suggests that particularly on northern walls, such cavities can be permanently damp and so should be left untreated to prevent tie corrosion, mould, or frost damage (particularly where repointing with inappropriately hard mortars may have exacerbated moisture problems).

Iwaszkiewicz, et al. (2010) convey the challenge of treating hard-to-treat cavity buildings and outline many complexities of using SWI in these buildings (as well as some advantages). Their report contains useful pre-installation survey checks.

2.5.4.10 Fire

Precautions made by Energy Saving Trust (2006a) include observing fire risk and hot surfaces or points of ignition and ensuring that electrical cables are not covered by insulation without guarding (since PVC sheathing may degrade, particularly if in contact with polystyrene). It also discusses the use of SWI and fire breaks in multi-storey buildings.

2.5.4.11 Other hazards and recommendations

Energy Saving Trust (2006) also provides advice on avoiding bi-metallic corrosion, and urges that DPCs are not bridged by SWI and that structural movement joints are not covered. It also suggests that specifiers consider the embodied energy of materials. Site hazards such as particle spread from working with polystyrene insulation are also identified in this document. In line with research on limiting overheating (Gupta & Gregg 2012; Oikonomou et al. 2012; Energy Saving Trust 2010b), Honour (2010) suggests that render should be light coloured to limit solar gain (also reducing stresses in fabric).

2.5.4.12 Durability and maintenance

Noteworthy disadvantages of SWI include reduced impact and abrasion resistance of surfaces and vulnerabilities to moisture ingress. King and Weeks (2010) recommend that insulation and render be reviewed regularly as part of maintenance. Energy Solutions (n.d.) provides a summary of knowledge about SWI installation and notes the risk of impact damage to EWI; it suggests this may be mitigated with thicker render at ground level. Energy Saving Trust (2006a) suggests that to minimise risk of damage, reinforcement is provided for wet render or dry systems in vulnerable areas (ground floor, around entrances and vehicle access). It also suggests potential benefit to ensuring that surfaces are easily over-painted in the event of graffiti damage. The guidance suggests that dry finish systems with smoother surfaces tend to require less maintenance than wet systems, and that specification should account for orientation, exposure, risk of algal growth, pollution contamination, and contamination from flues or fan outlets.

2.6 Summary

There is a clear need for SWI in order to meet national energy and climate targets and hence there has been in recent years the beginnings of a concerted effort by government to trigger investment and growth in SWI retrofit. The UK housing stock contains many millions of homes which would benefit from SWI and in light of targets are candidates for SWI. Retrofit of these homes can potentially deliver not just significant reductions in operational energy demand, but also can lead to improved occupant health, comfort and decreased expenditure on fuel.

This chapter has shown that when specified and installed in accordance with scientific understanding of best practices, SWI can provide a vitally important role in improving existing building stock. In parallel, it has also described the multitude of unintended consequences which may arise from poor practice.

This research examines the factors that influence delivery of SWI. The development of research questions (presented in the following chapter), findings and analysis should be read with an understanding of the context which has been presented so far.

3 Development and context of research questions

3.1 Overview

This short chapter begins by outlining the existing understanding of the SWI industry found before the field work commenced, and wider research of the refurbishment and retrofit industry. It concludes with a description of the iterative development of research questions.

3.2 Pre-existing understanding of retrofit industry

No publications offering an overview of the UK SWI industry were found in research. From experience in building trades work and previous academic work, the 'industry' was understood to be an atomised and loosely formed system (this understanding did not shift during the course of research). Insulation manufacturers are almost exclusively large multinational organisations. System suppliers and manufacturers of ancillary products range in size from the multinational manufacturers of insulation themselves to national and even small or micro enterprises.

3.2.1 Anecdotal reports of poor installation quality

At the earliest stages of the project, some anecdotal reports from construction and energy experts suggested that UK SWI practices were generally poor. As research progressed, further reports described a legacy of widespread poor build-quality. In addition to indications from experts, a newspaper article (Smith 2013) reported frustration among residents whose homes were included in an area-based retrofit project in South Wales, citing complaints of "dozens of homes… left with leaking roofs, ruined gardens and escalating damp issues" since EWI had been installed (Figure 11, overleaf). Subsequently, observation suggested that the persistence of quality defects in installation (both aesthetic and functional) could in fact be observed readily across a number of settings.

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Tenants vent their concerns over housing insulation project

'Corners have been cut... it can't happen elsewhere'

Mark Smith
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NEIGHBOURS have criticised a housing association for keeping them "in the dark" over a half-completed, multi-million pound housing insulation programme.

Around 50 tenants of RCT Homes in Penrhys held a public meeting at the estate's Llanfair Church on May 29 to discuss their "botched" cladding jobs.

They claim dozens of homes have been left with leaking roofs, ruined gardens and escalating damp issues since the external wall insulation project was launched in March 2012.

Families say painting jobs have been left unfinished, gates have been damaged and contractors have used "creative and downright dangerous" methods of carrying out jobs.

Some even claim workers have had to borrow tools from the public after turning up without proper equipment.

In response, RCT Homes has apologised and admitted the work carried out by contractors was not up to standard. In a leaflet to tenants last year, RCT Homes said they aimed to get contractors and subcontractors to refurbish all properties in Penrhys with better insulation by the end of September 2012.

As well as increasing energy efficiency, they said the improvements would give the distinctive 1960s housing a "more modern appearance."

But some residents say the £2.1m project has had the opposite effect and made homes even colder – because the insulation was not installed properly.

Scaffolding still exists on several properties 15 months after the work was set to be completed. A group, called Penrhys Voice, was set up earlier this year to act for residents of the estate.

Steven Trythall, chairman of the newly-formed group, said: "We simply want to highlight some of the problems that exist, hopefully get some action and prevent the same mistakes from happening elsewhere.

"There have been many corners cut in order to ensure all work started before the deadline so no fines were incurred.

"This has resulted in lower quality workmanship and the introduction of a number of shortcuts, including at least four different methods of application to speed up the work and reduce costs.

"There is an underlying feeling that residents' concerns are falling on deaf ears."

Residents say various sub-contractors have been ushered in to "hide" mistakes rather than treat them.

Leon Moss, Penrhys Voice Treasurer, added: "As a group, we need to be taken seriously, and we are going from strength to strength.

"We want Penrhys to be a positive and safe environment for our children."

Last year, RCT Homes submitted an outline planning application to develop around 100 privately-owned homes on 11 acres of derelict land near the current estate.

Partners involved predict total investment – over five years – in the Rhondda village could reach £40m.

But representatives from Penrhys Voice have treated the news with great caution following the "disappointing" external wall insulation work.

An RCT spokesman said the project has been difficult for all concerned.

He said: "It has taken a lot longer to complete than we forecast, not least because of last year's extremely poor weather.

"We have held a number of meetings at Penrhys throughout the project to enable tenants to raise their concerns and we have investigated them all.

"Where we've found the concerns to be well-founded, we've worked closely with our contractor to try to address them.

"It's clear that the contractor's performance on the project has been below the standard we'd hoped for and we are disappointed by that. The contractor now has additional workers at Penrhys, working on the clean-up process and jet washing affected areas to get them looking tidy again. However, none of this excuses the fact our tenants have had to put up with disruption and inconvenience. We'd like to apologise to them and thank them for their patience.

"If any other tenants at Penrhys have concerns about the quality of the work carried out on their homes, or any problems they believe the work may have caused, we want to hear from them so that we can sort it out. Where mistakes have been made we will not hide them; we will fix them."

Penrhys Voice has set up its own constitution and plans to stage regular community meetings.

■ Community members in Penrhys have joined forces to ensure their voices are heard

■ Penrhys estate is in the middle of an external wall insulation programme

■ From page 1

Mr Davies added: "It is shocking that a cannabis factory is found on a busy High Street but I still think the police could have acted sooner."

Police Inspector Andy Jones, said: "Early indications are that this operation was capable of producing cannabis worth thousands and it would have been destined for streets of the Rhondda.

"Inquiries are ongoing to locate the owner.

"Wherever a cannabis factory may be set up, there will always be somebody living, working or passing through that area, in a position to raise the alarm.

"We cannot comment on individual cases, but we can confirm intelligence we get from the public must be developed further before we can apply for a search warrant.

"Officers were led to this building to investigate an attempted burglary, and as they were doing so, they acted on obvious telltale signs that they were dealing with a cannabis factory as they entered the property."

The day after the cannabis factory was discovered in Trowbridge, a much larger one was found in Aberllechau Road, Porth.

Around 200 plants covering three separate rooms were seized by officers and later destroyed.

"We have an excellent example of just how public information is developed and acted upon, with the discovery of a cannabis factory the day after this particular find, in Aberllechau Road."

■ Nguyen Vhodai appeared at Pontypridd Magistrates' Court charged with producing a controlled drug and illegally extracting electricity in relation to the Porth incident.

■ Magistrates committed the case to Merthyr Crown Court.

Figure 11: Newspaper article reporting "dozens of homes" left with problems after EWI installation in an area-based project. (Permission to reproduce original content granted by copyright holder)

3.2.2 Prior research of refurbishment and retrofit industries

Evidence of performance gaps in energy projects not including SWI has been shown to be robust (Zero Carbon Hub 2014). Despite a dearth of research in SWI, a relatively mature strategy developed across government and industry to improve sustainability in the existing built environment with SWI retrofit has been informed by considerable theoretical research and understanding. The scientific understanding of *what* needs to be done is well-developed. Largely under-researched, however, are questions about *how* 'technologies' are applied in practice, *what* the significance of this is for performance-in-use and *why* these practices exist as they do.

3.2.2.1 Emerging acknowledgement of the role of 'middle actors'

Bordass and Leaman (2013, p.5) describe a performance gap in retrofits and note, "As differences between expectation and reality have widened, confidence in professionals has diminished."

Increasingly, researchers identify a 'middle ground' between policy and practice and between design intent and practice and recognise that what occurs there is of great importance for the performance of retrofits. In this 'middle', the notional performance that is intended becomes shaped by a multitude of factors, among which are the interactions of technologies with the building fabric, with other technologies, and with the building users.

Janda and Parag (2013) understand that change (i.e. social and technical innovation) is often understood without recognition of the impact of -- and opportunity presented by -- the 'middle' actors in low-carbon innovations and practices. They define these middle actors as including trades, professionals and suppliers (as well as building operators, utilities, communities, business owners, and local governments). They describe upstream influence from middle actors (i.e. to policymakers), noting groups, companies or trade organisations may directly or indirectly influence policy through consultation or publication or as "individual members of a profession may serve as an expert on a government commission…". The growing understanding of the importance of the 'middle' in shaping the delivery of energy technologies and designs is reflected in recent doctoral theses by Zapata-Lancaster (2014) on designers, Wade (forthcoming) on heating system installers; and Killip (2011) on the RMI industry, and in other work by Hill and Lorenz (2011) on property professionals, and Schiellerup and Gwilliam (2009) on property agents.

3.2.2.2 Sustainability and the call for 'new professionalisation'

In the midst of this research, work exploring the potential for evolution in the construction professions in relation to the low carbon and sustainability agenda was published in a special issue of Building Research & Information titled 'New Professionalisation' (2013, Volume 41, Number 1). This offered a rare concentration of debate – essentially new – which touched on many of the themes that were emerging in this research.

In their introduction to the issue, Bordass and Leaman (2013, p.1) state that in the context of a clear need for improving the sustainability of our built environment, "progress in achieving better performance in use has been disappointing." They state, "Something seems to be wrong. Are current policies, institutions and delivery systems fit for purpose?" The New Professionalisation issue highlights an emerging recognition that built environment professionals (and professionalism) are an as-yet under-researched element of the sustainable built environment research domain.

The special journal issue draws attention to an emerging research agenda related to retrofitting and installers. Bordass and Leaman (2013, p.6) point to the need for further research on "links between practice, research, education, policy-making and the public". This thesis steps into this space, and advances a set of questions slightly outside of the special issue's focus as it seeks to understand installation and specification in the context of links Bordass and Leaman describe. Discussion in Section 9.5.6 and elsewhere in Chapter 9 addresses the implications of work presented in this issue.

3.2.2.3 Multi-skilling and the role of 'system integrator'

Informed by the concept of systems of professions (Abbott 1988), and drawing from a focus on the middle ground, a small group of authors have recognised several truths about energy refurbishment. First, they understand that much of this work is carried out by members of the 'biblical trades' (e.g. plumbers, electricians, plasterers and carpenters). Second, they recognise that the sustainability agenda requires skills and knowledge which are currently relatively scarce in the wider construction industry, but do exist in some specialisms outside of the industry or at its periphery. Third, they see that resolving this situation will require the creation or 'negotiation' of new professional roles and identities. Finally, they recognise that the prevailing model of work in the industry has to date evolved conservatively.

Two concepts have emerged from their considerations: 'multi-skilling' and 'system integrator'.

Killip (2011, pp.250–251) differentiates between 'multi-skilling' and 'integrator' roles. He offers a case study in which heating engineers were trained to insulate under floor boards during the course of their normal work. This is precisely the sort of jurisdictional encroachment which literature has long regarded as anathema to stability in 'systems of professions'. While adding the task to a heating engineer's remit is a rational idea, to anyone with insight into the dynamics of trades work it will seem highly impracticable. Killip recognises inertia and "strong counter-arguments" for the idea rooted in the "conservativism of the trades" (2011, pp. 203; 251).

Hughes and Hughes (2013, p. 32) outline how "normative and cultural-cognitive frameworks" are fundamental to role definition and identity in refurbishment. They suggest that the sustainability agenda calls for new professional and disciplinary crossover. Similarly Janda and Killip (2013, p.43) argue that "competencies that are well established within one profession may need to be expanded to become the preserve of other roles". They suggest that energy efficiency work may require a new leadership role, which they describe as an "integrator" who would work between the various parties on a traditional project.

The concept of a "system integrator" first appeared in a publication by the World Business Council for Sustainable Development (WBSCD) (2009, p.61). It describes “workers with the skills necessary to manage and integrate [different aspects of retrofitting]. They would be able to assess energy-efficiency requirements and develop a whole-house plan, select appropriate contractors and manage the retrofit process”. The concept has been given considerable notice in recent years by Janda, Killip and others (Janda & Parag 2013; Janda et al. 2014; Janda 2011; Killip 2011; Nösperger et al. 2011).

3.3 Research questions

This research was undertaken to examine current practices in light of a reported legacy of inconsistent build-quality and performance gaps in UK domestic SWI retrofitting hypothesised and reported anecdotally in industry and research communities. It sought to improve understanding of practices, which was an issue about which essentially no literature had been published. SWI installation at the time the project started was very much at the fringes of the construction industry with low numbers of completed projects.

Very little concrete knowledge about SWI practice existed and no pre-existing academic theory outlined causal factors. Without theory to test or published observations on which to develop new questions, an interrogative and inductive approach that would develop questions and require no assumed knowledge of industry practices was strongly appealing.

Emerging from early discussions and literature review were two fundamental questions about practices which remained unanswered:

- Could early anecdotal reports of poor practice be confirmed or rebutted by experts inside or outside of industry?; and
- What exactly would be considered 'good' or 'bad' practice?.

It quickly became clear that the SWI industry and the landscape in which it operated were changing rapidly. For practical reasons, the boundaries of the research would necessarily be a small subset of industry and its immediate context.

Through the iterative process of research described in this thesis, the following questions were developed:

- By what standards could practice be evaluated as 'good' or 'poor'?;
- In an observed population of the industry, what characteristics of practice could be observed?;
- What might explain or contribute to good or poor practice?;
- Were models for improving practice available elsewhere in the UK construction industry or outside of it?; and
- What actions might enable improvement in practices?.

The research questions should largely be read as open-ended; the intent of this thesis has not been to offer definitive explanations or characterisations of the SWI industry at the time of research. Rather, the work's value lies in posing new questions and framing responses to these. It should complement the reading of existing research and augment future primary research and allow secondary analyses.

3.4 Summary

By the end of this chapter, the reader has been introduced to the background information and research context and to the research questions that have been developed against this context and through iterative analysis. The following chapter will introduce key literature which has informed analysis of findings.

4 Literature review

4.1 Overview

This chapter introduces a range of literature that provides the context for interpretation of findings presented in this thesis. It begins by outlining the development of a definition of quality which developed iteratively during reading and field research. It then reviews literature on quality control and construction management. A wide range of literature related to knowledge exchange and vocational training provides historical and theoretical contexts which have informed analysis. Finally, the topic of systems of professions is introduced.

4.2 Definition of quality

This thesis develops a set of theory by observing and studying phenomena in a wide variety of settings. To answer the questions this research has addressed, it has been necessary to describe, evaluate, and analyse retrofits within their wider contexts. From early stages through the field research, a concept of quality has been developed iteratively from literature review, observation and reflection to provide a framework for interpreting findings.

Concepts of quality are very often idiosyncratic. They tend to be comprised of subtleties, complexities and interwoven factors.

In common usage, 'quality' carries wide-ranging definitions. Any attempt at a neat definition betrays so many facets of meaning that the word -- in its lack of specificity -- starts to become unserviceable. This tendency to absorb breadth of meanings, however, perhaps also makes the word useful. 'Quality' presents a contraction of diverse and rich meanings, and this offers practical advantage to this thesis. Nonetheless, it will be useful to the reader to delineate the nuances intended to be captured by the word.

Firstly, quality is used here to refer to any of a virtually countless array of phenomena observed in the research. It does not refer strictly to materials or processes. Quality should be understood to be the product of innumerable small-scale decisions made in the process of delivering retrofits.

Secondly, the most common significance of 'quality' in common usage -- the assessment of excellence or the relative success in achieving an ideal – is intended to be communicated here.

Quality -- as an assessment of excellence or an objective to be achieved -- is used here to connote:

- achieving the aims stated by those driving or controlling retrofitting;
- characteristics of production, process, or product that are desirable to one or more stakeholders (i.e. implicit aims), at any stage of the lifecycle of an installation;
- efficient use of financial investment;
- minimisation of harmful impacts to environment, people or building fabric;
- efficacy and efficiency in processes and structures – such as working practices, site management, or process management; and
- social benefit and positive contribution to local trade skills, or economic resilience.

More explicitly, ‘quality’ is used to convey particular attributes or achievements such as:

- robust composition of construction – what is commonly captured in the term ‘build-quality’;
- construction make-up consistent with objectives for fabric performance;
- SWI specification appropriate for meeting the objectives detailed in the list above; and
- compliance with manufacturers’ guidelines, relevant legislation and regulations, guarantors and warranty requires.

There is correspondence between the concepts of ‘quality’ and ‘value’. For a building, value may be rooted in the degree of ‘build-quality’, its geographic location, its cultural or even sentimental worth, or more obviously its financial value (Section 2.3.4).

Quality also has a clear relationship to sustainability. Working practices that exhibit efficiency and efficacy, and deliver robust built environments have a strong correlation to the environmental, social and economic elements which comprise common definitions of sustainability (Section 2.4.3).

In the many layers of meaning our language embeds in ‘quality’, there is also an evocation of durability and longevity. Quality in construction matters because, as Goldberger (2009) reminds us, buildings -- even in their most banal forms -- are statements of society’s values. John Ruskin famously argued for robust and long-standing architecture; he wrote (Wheeler & Whiteley 1992, p.221):

> …when we build, let us think that we build for ever. Let it not be for present delight, nor for present use alone; let it be such work as our descendants will thank us for, and let us think, as we lay stone on stone, that a time is to come when those stones will be held sacred because our hands have touched them, and that men will say as they look upon the labour and wrought substance of them, “See! This our fathers did for us.” For, indeed, the greatest glory of a building is not in its stones, nor in its gold. Its glory is in its Age…

This may be difficult to reconcile with contemporary attitudes toward buildings and the role we assign to buildings. Nevertheless, it is as an ideal which is reflected in the notion of quality. SWI should improve buildings in line with the imperative that our built environment is made more energy efficient and conducive to occupant health (Section 2.3) (and correspondingly it should not lead to unintended consequences). Ruskin’s worldview reflects an expectation that buildings should endure for generations and thus their value is in large part derived from their durability and their ‘reflection’ of those who built and altered their physical form during their existence. We cannot reasonably expect many of the homes being retrofitted today to last for as long as those Ruskin venerated; indeed many candidates for SWI are homes that were knowingly built to low quality standards during periods of economic recovery, or population expansion or relocation (i.e. inter-war and post-war periods). Nevertheless, Ruskin's worldview is not entirely obsolete. While SWI -- particularly in the context of mass housing -- need not be packed into Ruskin's ideal of sacrosanct architecture, we should marry the ideal of a resilient, energy efficient, healthy and comfortable built environment with the mindfulness, intention, and preservation of value that Ruskin espoused. This is an ideal that should be reflected in the execution of SWI. In turn, against Goldberger's reminder that our buildings are reflections of our values, we can expect that if we are placing value in resilience and sustainability, our built environment will embody this. In light of all of this, the nuances of meaning attached to quality should be understood to include intentionality, process, functionality (i.e. utility and commodity), and effectual management.

Thought leaders in manufacturing and construction management imbue 'quality' with meanings of process and conformance. Winch (2002) asserts that 'quality' has at least four meanings and delineates 'quality of conception', 'quality of specification', 'quality of realisation' and 'quality of conformance'. He argues that by broadening the meaning of quality, the word reflects interests of stakeholders other than the contractor/manager.

Winch's notion of conception quality encapsulates attributes such as 'elegance of form' and 'contribution to urban culture'; relevance here to SWI might be drawn to aesthetic value, conformity to vernacular form or materiality. By 'quality of specification', Winch refers to functionality and fitness for purpose, which have clear relevance to SWI -- so too does 'quality of realisation' (adherence to programme, budget and delivery). 'Quality of conformance' is perhaps a more nebulous concept used to describe fulfilment of prescribed intentions. It has clear relevance to the notion of the performance gap, and quality of conformance then suggests achievement of design intention. It also suggests adherence to accepted tolerances or prescribed practices, and to the absence of defects. In contrast to a more conventional definition of 'quality' in management (based on time/cost/performance), Winch argues that it should include the requirements of stakeholders other than the contractor.

Winch was writing on the narrow focus of construction management. Ruskin was writing to argue for a closer connection with our past. This thesis addresses a wide range of topics. Quality here serves as a marker for relative success against an equally broad range of metrics against which the ideal delivery of SWI can be assessed. It reflects design and conception which is appropriate to the drivers of retrofit relevant to all stakeholders, and a realisation in construction which conforms to design intent. The following sections provide further contextualisation of 'quality'. It is discussed in relation to construction management, the 'doing' of work, craft, identity, and environmental sustainability.

4.2.1 Environmental impact and life cycle assessment

Quality should be understood in relation to 'net' environmental impact of the materials and processes used in SWI.

All building materials and processes consume energy, water, and raw materials. In turn, across the lifecycle of a SWI retrofit, materials and processes can be assessed for embodied energy and impacts. To better understand and compare the environmental impact SWI retrofits, it is useful to disaggregate impacts in each constituent phase of building material manufacture and retrofit process. By examining these through a life cycle assessment (LCA) framework, a complete analysis can be formed. This will include an evaluation of raw materials and extraction processes, pollution and production of hazardous materials[26], pre- and post-manufacture recycling, end-of-life scenarios, and energy use in production and transport (Figure 12, overleaf; Figure 13, overleaf; Figure 14, overleaf).

LCA accounts for service life, therefore a material which is more durable but more ecologically burdensome to produce may be proven preferable. This is an important part of LCA, albeit one which can introduce an element of imprecision to assessment (Anderson et al. 2009). Understanding the implications of durability of materials and of build-quality is pivotal to determining accurate figures for service life (Lewry & Crewdson 1994).

Comparing impacts of different materials or construction systems through a life cycle assessment is a notoriously difficult and messy exercise. One useful example of this is to compare a conventional foam insulant to sheep wool insulation. The manufacture of foams may use hydrofluorocarbon (HFC) blowing agents. The use of HFCs in and of itself may entail a global warming potential (GWP) so high that net GWP reduction

[26] Some insulation products and constituent parts of SWI systems have significant pollution and toxicity profiles. Although a review of these is not possible within the available space in this thesis, it should be understood that included in the 'environmental impact' of SWI is chemical pollution in the form of novel entities, toxic emissions to air or water in the form of persistent and long-lived organic pollutants, synthetic organic pollutants, trace radioactive materials and heavy metal compounds. Although the environmental impact profile of most materials in SWI is no worse than many other building products (which can of course be significantly polluting), it should be understood that many materials present significant tolls on the environment.

may not be achieved in the lifetime of the insulation (perhaps 30 years) as the blowing agent escapes from the foam into the atmosphere. Sheep wool, on the other hand, may on first approach seem to be an ideal material; it is an agricultural product, supports local scales of production, requires very little manufacturing input, and can be returned to the biological cycle without processing at the end of its useful lifespan. However, examine foam produced with low-GWP blowing agents against sheep wool imported from a different continent and the balance of impact may shift. Foam insulants offer lambda values which are far superior to sheep wool (e.g. 0.020 compared to 0.035). To achieve a comparable U-value with the two materials then would require 75 per cent more wool by volume. Not only would this require greater volume to be transported, but it may reduce useable living space, require alterations to the building fabric to accommodate the larger volume; additionally, wool is typically installed into a framework (most likely retrofitted) whereas foam can be fixed directly to the wall and even dry-fixed depending on specification criteria. This comparison is a simple demonstration of the complexities which LCA illuminates. It is important that assessments of material 'footprints' are comprehensive and account for impacts across the life cycle rather than capturing only those in manufacturing. This is not to understate the case for selecting materials produced through less-intensive processes, but this selection should always be based on holistic assessment.

A significant body of data for LCA of energy efficiency refurbishment projects already exists and research of this topic is relatively mature. Moncaster (2013) examined embodied carbon and carbon savings in SWI (mineral wool EWI, graphite impregnated EPS EWI, glass wool IWI and PIR-laminated plasterboard IWI), and found that all products offset embodied carbon in less than 13 months of operational savings.

Carbon footprinting of construction products is an area of significant research (Doran & Anderson, 2011; NHBC Foundation et al. 2011; Hammond & Jones, 2011). Significant work comparing carbon savings in new build to refurbishment has explored the issue of embodied carbon (Mackenzie et al. 2010). Other work has focused on site pollution and management of the construction process to control environmental impact (Grimwood et al. 2003; Dickie & Howard 2000; Bennett 2003). These have contributed to guidance on responsible sourcing of construction products, including the Framework Standard for the Responsible Sourcing of Construction Products (BES 6001) (Young 2009) and the Green Guide methodology (BRE 2015).

Properly specified and installed insulation should realise a vast environmental benefit over its lifetime compared to those embodied in its manufacture and installation. Nevertheless, there are significant disparities in ratios of operational energy savings to embodied energy (among other environmental impacts) for various insulation products and systems. Poor installation practice, inadequate detailing, or limited physical resilience in materials can all have significant impacts on the service life and performance in use of insulation materials. For instance, moisture ingress may lead to diminishing performance or even greater problems such as freeze-thaw damage, interstitial condensation, mould growth or rotting of structural members. These have correspondingly grave implications when examined through LCA. With shortened service life or poor performance, replacement intervals will be reduced; triggering waste and requirement for new materials. Similarly, if the ratio of embodied energy to operational energy savings is poorer, the initial cost-benefit calculations of insulating walls must be reconsidered.

The implications of specification and installation method in retrofits for net environmental impact form a key component of ‘quality’ in this thesis.

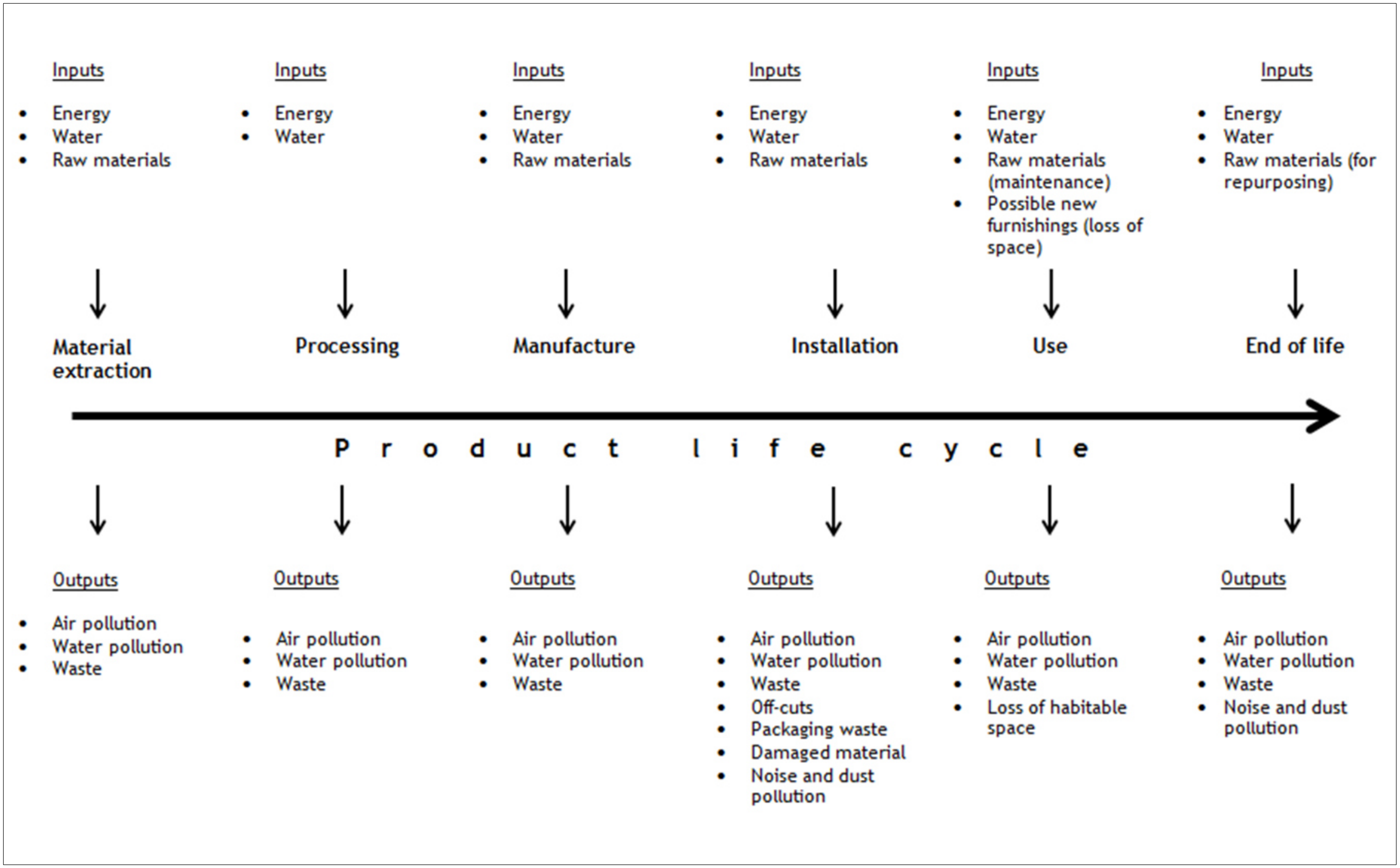

Figure 12: Impacts in the product life cycle

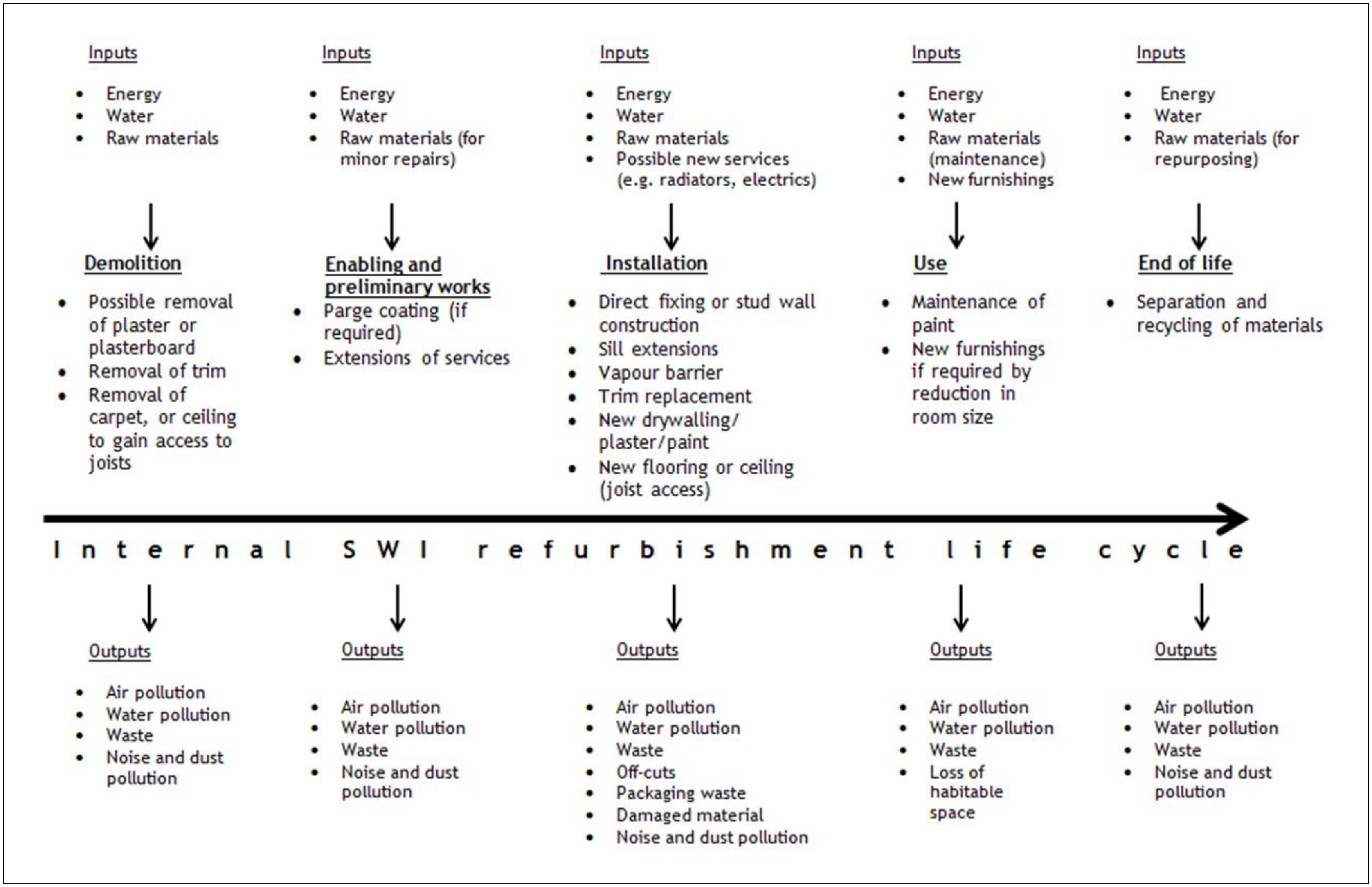

Figure 13: Impacts in the life cycle of internal SWI refurbishment

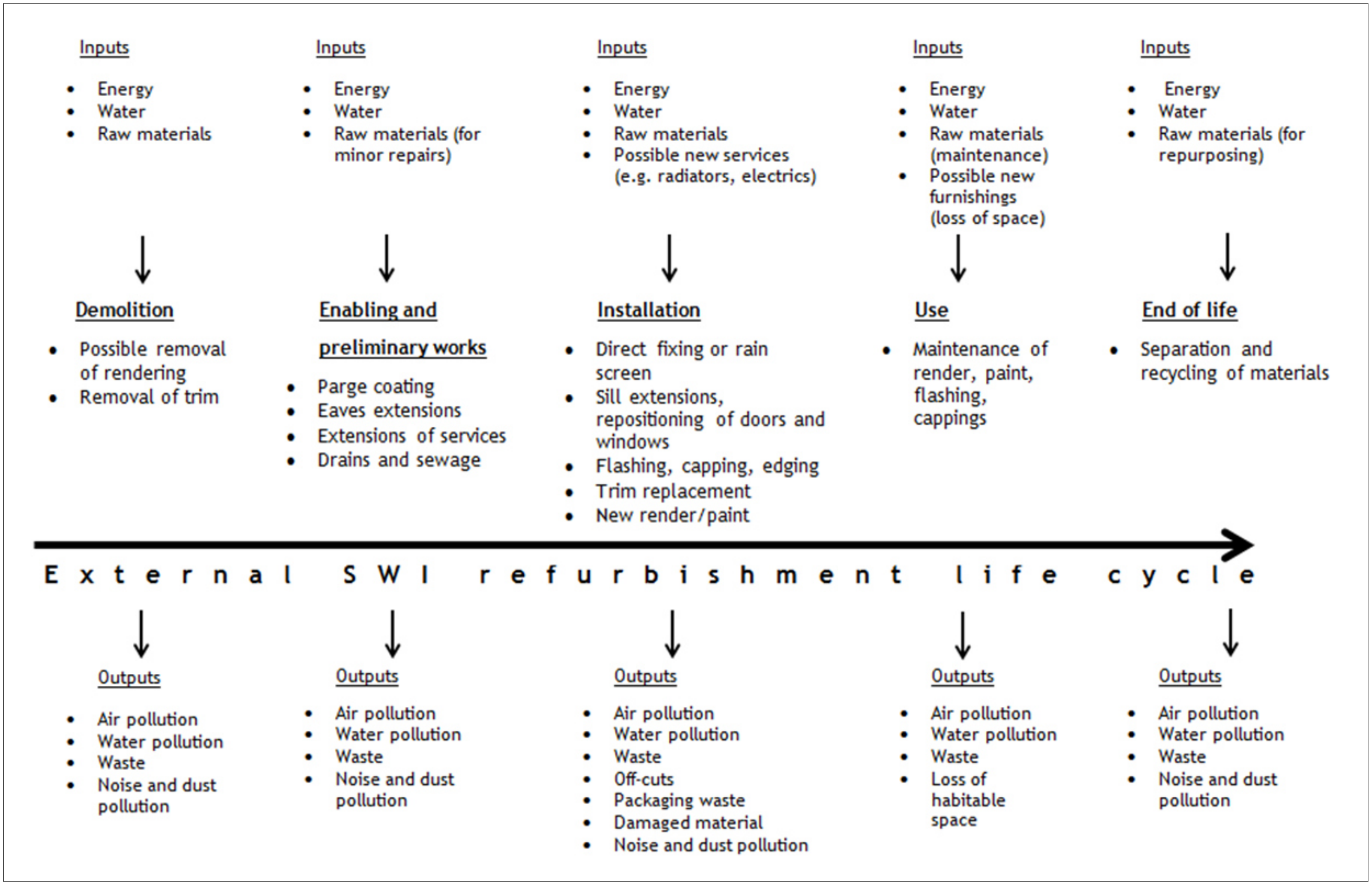

Figure 14: Impacts in the life cycle of external SWI refurbishment

4.2.2 Capital and life cycle cost

The assessment of quality made in this thesis includes some reflection of relative cost. Capital cost of SWI is known to vary widely and there is significant disagreement in literature regarding cost ranges. Many cite a range of £5000-£10,000 per house for IWI and £7,500-£15,000 per house for EWI. Other estimates cite a higher maximum as typical of UK work (e.g. £15,000 for IWI and £25,000 for EWI). The projects included in this research were typically charged at the lower end of these ranges. In the absence of an authoritative published study outlining the factors of SWI costs and offering average market prices, it is not possible to draw interpretation from the charges for projects included here; this information is provided for reference only.

Costs vary significantly depending on labour, the construction and thickness of the original wall, access, co-location of multiple sites (i.e. efficiency of scale), condition of original wall, and choice of insulant, insulation system (for instance a studded IWI system will cost more than a directly fixed one) and finishing materials. Moreover, added costs can be substantial for steps such as disconnecting or relocating building services, kitchen and bathroom fittings, making good trim or floor coverings, roof extensions, or windows, doors, garden walls or other structural components. Conversely, many costs can be reduced or amalgamated by combining SWI retrofit with improvements such as renewing plaster or render, painting or other refurbishment.

Whole life cost takes account of future changes in energy price and climate conditions, assessment of risk (including vulnerability to future weather events), requirements for maintenance (or reduction of maintenance duties), loss of interior or exterior space from the insulation system and externalities such as thermal comfort, health benefits, aesthetic change, and property resale value. To many, the perceived lack of data, uncertainty in data sources, or unavailability of resources to assist in developing calculations is likely to present an obstacle to evaluating SWI retrofits by measures of whole life cost. Moreover, variability in future value of energy price or lending interest can account for dramatic differences in Net Present Value (NPV) (Rasmussen 2010). Due to the significance of life cycle costs relative to capital costs, however, it is arguably a much more important measure.

Although this research does not calculate costs for observed practices, discussion and analysis of findings – which are phrased in terms of 'quality' do take account of assessments of relative benefit achieved for given capital costs, and possible implications of observed phenomena for whole life costs.

4.2.3 Social and economic impacts

Social and economic benefit to owners and occupants and collective society forms an important part of the quality of a SWI retrofit. Typical potential benefits of retrofits were described in Section 2.4.3. Discussion of quality in this thesis is partially based on relative achievement of these social and economic benefits.

Householders may not always recognise a worthwhile cost-benefit ratio, whether in economic terms or other forms of benefit. Research has found that issues such as aesthetics, lifestyle, life events, energy efficiency and finance often influence decisions to undertake energy refurbishment (Haines et al. 2010). Energy Solutions (n.d.) argue that installation of IWI may be disruptive to occupants and that relocating existing fixtures, architectural details, and fittings such as radiators and electrical installations may be undesirable. The importance of these issues in ‘trigger’ decisions is also noted by many other authors (e.g. Energy Saving Trust 2006; Honour 2010).

4.2.4 Buildability

Quality also connotes the utility of retrofit systems and technologies. Materials and systems of assembly should be easy to use for installers. This is an attribute which is commonly referred to as ‘buildability’. Killip (2011, pp.219–220) broadens this definition and presents an approach to assessing utility of technology. He argues, “For SME construction working on RMI, key elements of the ‘buildability’ idea are that building work needs to be made up of products and methods that have all of the following characteristics:

> Practical – solutions need to be relatively simple and quick to implement
>
> Replicable – a refurbishment package needs to be something that can be installed many times over by the general population of installers, rather than being the preserve of some kind of elite
>
> Affordable – unit costs may well come down over time and can be influenced by policy, but at any given time the solutions need to be within the reach of a viable market, or provided with suitable incentives

> Reliable – products and systems need to work well and be robust
>
> Sellable – the costs and benefits to both customer and installer need to be readily understood
>
> Available – specialist products that take weeks to order will not find favour among the mainstream: developing product supply chains is key
>
> Guarantee-able – installers make their reputation on delivering things that work and, conversely, will abandon products or methods which lead to repeated call-backs and complaints
>
> Profitable – firms need to be able to make a living from it"

These elements of buildability form a part of the notion of 'quality' considered during observation and analysis, and they are revisited in the discussion section of this thesis.

4.2.5 Construction management and meaning of quality

'Quality' is a multidimensional and evolving concept in construction management literature. Lavender (1996, p.284) argues:

> There is often a misunderstanding of what is meant by 'quality'. It does not necessarily mean something which is good. Rather, it means conforming to a standard or requirement which has been set or which is expected. Therefore, quality is about a product or service being fit for the purpose expected by the client or customer. Quality standards may be set at any level – high, medium or low. The important thing is that the outcome matches what is expected.

Other authors use 'quality' to discuss organisational capability. Harris and McCaffer (2013) argue that 'quality' refers to more than simply a product's features, but instead reflects processes of organisation, production and pre-production dynamics. They acknowledge fitness-for-purpose of procedures, process speed and flexibility as central components, but add attributes such as 'respect for people', 'continuous improvement', 'response to change', and 'fault detection and prevention'. Harris and McCaffers' concept of organisational capability suggests that a critique of SWI delivery should examine not just the nature of the delivered product, but the broader processes and impacts of management. Construction management must not simply deliver works within expected standards and benchmarks; it must also secure organisational efficiency and efficacy.

Janda et al. define 'quality' in low carbon refurbishment as including not just the physical work and design, but also the "quality of communication" (Janda et al. 2014). This is reflected in Fryer and Fryers' (2004, pp. 14-15) analysis of four 'new Ps of management' which relate to 'post-industrial' ways of working. They argue that modern management must reflect post-industrial changes in society by shrinking middle management and transitioning toward greater management efficiency. This transition toward greater management efficiency can be achieved by the "de-layering" of middle management. They differentiate between technical and strategic concerns for managers and assert that construction necessitates flexible and self-reliant managers.

4.2.5.1 Workplace culture and leadership

A reified discussion of quality in the context of construction should include the nature and effect of workplace culture. There is a long (though not extensive) history of construction management research examining refurbishment. Much of this has identified the important role of effective leadership. Egbu (1999), for instance, found that among 32 large refurbishment organisations in England, leadership, motivation of others and communication ranked alongside decision making, forecasting and planning as important attributes in projects.

Lavender (1996) argues that "power cultures" are commonly found in small firms and display hierarchical structure in which a powerful leader or 'centre' maintains control over all other agents. In Hofstede's (2001) important work, he discusses individualism and collectivism and introduces 'power distance' to measure distribution of power between leaders and subordinates.

In much of today's construction industry, a growing emphasis on professionalisation and increasing sophistication of management strategies can be observed (Bresnen & Marshall 2001). Yet this is highlighted in the context of non-domestic and new-build construction and literature has not convincingly showed trends – either toward professionalisation or conservativism and anti-professionalisation in domestic RMI. This research addresses this gap and provides early evidence of construction management, leadership and culture in the context of SWI retrofitting.

4.2.6 Craftsmanship and the role of the trade union

Craftsmanship and workmanship connote the degree of skill and attentiveness with which a product is made or a job is done. The tradition of trade skills is conjoined with building and architecture to such an extent that historically there has not been a division between builder and designer.[27] To the extent that we can look to Greek and Roman cultures as progenitors of our own architecture and built environment, their entanglement of these two roles -– and the of the qualities of functionality and metaphysical significance in built forms -- is intriguing and instructive. This intertwining also appears in many built environment traditions outside of Europe. As we look at modern design and construction, it is perhaps little surprise that a deep disambiguation of the concepts has evolved in our language. Many of our buildings betray deep schisms between function and poeticism or delight.

In modern debate, we still wrestle with defining architecture. Is it, as in Buckminster Fuller's argument, remarkably close to manufacturing and product design (Massey 2009)? Perhaps rather, it is as the Swiss architect Peter Zumthor (2010) has espoused, a poetic process idiosyncratic to each building and site. If constructing our built environments is essentially manufacturing, then what is craft? We must ask the question: Do those who build and maintain our habitat have a responsibility to create pleasing structures or are they simply assembling functional products?

To answer these questions and improve our understanding of the context SWI installers emerge from, we should look to the evolution of today's builder; the SWI installer emerges from a long history. In European civilisation, the division of trades and the professionalisation of construction skills appeared in the middle ages. Guilds developed around carpentry, masonry, and metalwork before proliferating in other areas of construction and manufacturing. This is the origin of today's division of labour on construction sites, but it is also the ancestor of pride in (and protection of)) skill and 'craftsmanship' today. Importantly, this was also the time in which apprenticeship models became a dominant form of progression toward guild membership – thereby

[27] In Old English, an architect was known as a *heahcræftiga*, or 'high-crafter.' The word 'architect' that appeared in 16th Century usage was rooted in Latin and ultimately Greek words for 'chief' or 'master' and 'builder' or 'carpenter' (*arkhi tekton*). For the Ancient Greeks, *tekton* (or *techte*) reflected modern meanings of both 'craft' and 'art'.

separating those who ‘could’ and those who ‘could not’ practice a craft. This was the beginning of professionalisation of construction and design.

Moving forward to the industrial revolution and then to the post-war era, we see an evolution of practice much more recognisable today. During this era, economic growth skyrocketed and productivity reached its pinnacle during wartime and post-war years. In Britain, the construction industry underwent enormous growth and relatively new large corporate contractors expanded rapidly in response to the dual stimuli of rebuilding from the Blitz and post-Victorian urban rebuilding.

In interwar and post-war years, major corporations and contractors emerged and in many ways assumed the roles of the medieval guilds. They became the providers of work to craftsmen, custodians of standards of workmanship, and often the trainers and *de facto* authorizers of trade membership. Meanwhile, building in this period confronted wartime rationing of materials, often resulting in frugality in design and construction and poor quality (Ross 2002).

Organisations like the Wimpey corporation began to supply all elements of construction and design labour (White 1965). They supplied the multitude of specialist tradesmen necessary for contemporary work and even trained their workers and managed apprenticeship programmes. Like their Middle Age predecessors, the typical construction company in this era was managed and led by people with trades backgrounds.

Trade unions grew in strength in post-war years both in construction and across the UK industrial sector. In parallel with this, many municipalities began to employ construction workers directly rather than hire private contractors. Throughout the 1960s, trade unions became increasingly strong and began to be perceived as quick to conduct industrial action. Well-known examples of labour disputes include the 1965-1967 events during the construction of the Barbican (McGuire et al. 2013). In 1972, the newly amalgamated Union of Construction, Allied Trades and Technicians (UCATT) launched a major national strike in the construction industry (accompanied by the General and Municipal Workers Union and the Transport and General Workers' Union), demanding a minimum weekly wage and the abolition of casual day labour employment (i.e. Lump Labour). (McGuire et al. 2013)

Reaction to these developments, coupled with the rise of Conservative anti-unionism in the late 1970s, 1980s and 1990s created an environment in which corporate leaders chose to and were able to lessen the power of trade unions (Ball 1988). Many large contractors began to sub-contract work to so-called 'labour only' organisations in order to undermine the power of the large trade unions. Consequently, a large amount of the protection of workers which was provided by unions was stripped away as was their organisational power to protect membership in respective trades. Moreover, in an economic environment with increasingly tight margins, scope for apprenticeship schemes and training became limited. (McGuire et al. 2013; Finegold & Soskice 1988; White 1965)

There was, in all of this, a devaluing of the status of builders and a move toward mechanisation and deskilling. Compared to their ancestors, many in today's construction workforce are assemblers, rather than crafters and designers. Their jobs may require advanced skills, but above all else their role is to assemble pre-manufactured parts – most often to a specification or plan devised by someone in another job role. If anything, this trend is increasing: automation, modular construction and modern methods of construction (MMC) are propelling 'componentising' of the building process.

Workmanship and the responsibility of the constructor for extemporaneous problem-solving – while still crucial qualities – are deemphasised. For many centuries, buildings have displayed our mastery of nature and material; but we increasingly see a shift in the nature of this mastery. While we once cherished displays of skilful (literal) manipulation, today's ideal is an aesthetic of manufactured precision. If this is the case, then construction -- SWI installation included – should achieve the ideal fully and exhibit and embody technically expert assembly.

Craft is still a rudimentary part of many constructors' self-identities. Yet mastery and manipulation of materials is in many cases positioned less with constructors than with points higher in the supply chain – with the product manufacturer or system designer. In contemporary vernacular buildings, as in polite or landmark buildings, craft is increasingly shifted away from the building site – it appears in the uniform sweep and neat intersections of expanses built of factory-produced components.

Replacement of traditional labour-intensive and skill-intensive work such as site joinery or hand-applied finishing by off-site processes (e.g. factory-built windows and doors, uniform paints and renders, or mass-manufactured decorative details) may be explained by evolving industrial technology and by the expense of site labour in the UK. The standardised and technological form and aesthetic we have come to expect from our buildings relies on systematisation and assembly of parts from off-site. This is as true with SWI as it is in other construction work. Although evolution of SWI practice has not yet progressed to MMC, retrofitting is componentised and systematised to reduce the need for costly labour or sophisticated knowledge on site.

The devaluation of craft and the supplanting of craftspeople with modern mechanised industrial processes is reflected in a paucity of journeyman craftspeople and a general skills gap in craftsmanship which has been highlighted in industry reviews and academic literature (Miller et al. 2004; Green & May 2005; Department for Education and Skills 2005). 'Master builders' in the medieval sense are exceedingly rare in today's industry.

All of this begs the question of what we are left with in the dearth of traditional craft -- particularly if efforts to achieve the flawless precision of manufactured aesthetics are not successful. If we accept that an assembly of SWI from insulating board, smooth render, and industrially-produced trim components can produce beauty, then surely this must embody soundness, firmness and commodity. Without careful adherence to the proper method of assembly of these parts, and –- perhaps -– even without thoughtful selection of the aesthetic value of the various parts in the first instance, we are left with a built environment which offers nothing pleasing in its materiality, and nothing enduring in its commodity. This is the ugliest form of modern throw-away society: the use of ecologically expensive material toward a thoughtlessly short-lived and low-value end-result.

'Quality' in contemporary SWI is thus contextualised in the wider trends of the construction industry toward mechanisation and a turning away from a craft aesthetic. The trends in the industry that began in the inter-war years may have devalued craft skills and disempowered or devalued the trades in many ways, but this does not mean that builders and installers have been reduced to mere automatons. In fact, the need for care and attention to detail –- even in work which comparatively entails a greater reliance on simple assembly – is vitally important. It is necessary not just to achieving modern aesthetic ideals, but also to detailing and the minimisation of gaps between design intent and constructed form. The concept of 'quality' here reflects the central importance of these issues to the aesthetic and functional attributes of SWI across its lifespan.

4.2.7 Pride and process

The SWI product (the end-result as seen post-completion) -- despite componentisation -- still in some way reflects the hand of the installer. The ability to 'do good work' is not only reflected in the manner in which SWI is done, but the end-result.

Beneath this, there are knotty issues of motivation. Capability to achieve a high standard does not necessarily correlate to its achievement. Sennett (2009 pp. 244-246) recognises that quality 'becomes an issue' to the dedicated craftsman and is internalised within socio-organisational constructs in the form of 'quality-driven' cultural norms.

Fryer and Fryer note that "one of the critical factors in achieving effective quality and implementing good quality control is employees' attitudes towards it" (2004, p.145). Sennett goes further and identifies 'obsessional energy', which he argues eliminates exceptions not by process, but by pride and personal and sociological values. Obsessional energy results in the pursuit (or achievement) of quality in every *single* instance. Sennett finds this in the sushi chef and in the electronics manufacturer; he notes that perfect consistency and quality are not just achieved via processes, but become defining, intrinsic, personal and sociological values.

Textbook definitions of quality, in their focus on productivity, distract us from the critical issues of motivation, aspiration, and socio-cultural context. They ignore the social conditions necessary to cultivate cultures of pride which can result in 'quality'. Quality should be understood as simultaneously a phenomenon of the individual and of cultural context.

4.3 Quality and construction management

The mantra of "do it right and do it right the first time", has been internalised in many areas of construction, and reduction of rework and call-backs are dominant objectives. Logic would suggest that all areas of the industry would embrace this mantra in order to reduce costs. Basic familiarity with domestic and RMI sectors should make clear that this basic ambition has long been absent in many corners of the construction industry (Egan 1998).

Writers of textbooks on construction management place advanced quality management as a central concern. 'Quality management' is used to describe any of a range of techniques aimed at securing high standards of work with an efficient expenditure of resources. Harris and McCaffer (2013, p. 7) trace the evolution of quality management in construction over the past three to four decades from an inspection-based and intervallic approach, to the 'quality assurance' model still widely seen today (e.g. ISO 9000 standards family), and ultimately to growing adoption of Total Quality Management (TQM), in which all levels of a company are integrated in a system in pursuit of consistent reliability.

Traditional Quality Control (QC) is an 'after the event' approach which checks to see whether the finished product has conformed to expectation. QC "is regarded as a cost of production which has to be borne and is likely to be reflected in increased prices" (Lavender 1996, p.284). TQM, conversely, is rigorously systematic and is a 'before the event' approach and draws heavily on a concept of the 'internal customer'. Central to this approach, problems are 'designed out' before they occur (Lavender 1996, p.116). As will be argued in this thesis, TQM has important relevance to SWI, which requires that multiple stakeholders are aligned within projects.

Adversarial relationships between contractors, customers and supply chains are cited by many authors as a common obstacle to successful quality management (Fernie & Thorpe 2007; Fernie & Tennant 2013; Spekman et al. 1998; Tennant & Fernie 2013). Others acknowledge that problems lie equally within organisations, where staff have differing objectives or are not aligned toward the same vision or goal of quality. Fellows et al. (2009) discuss the merits of 'quality circles' which unify workers with first-line supervisors and their managers.

Civil engineering and commercial construction have been reasonably adept at adopting advanced quality management and numerous authors have held up management norms in manufacturing industries (e.g. automobile, aeronautical, and electronics) as models for practices (Huselid 1995; Lindner & Wald 2011; Winch 1998; Hobday 1998).

Harris and McCaffer (2013: p. 7) argue that quality management has "become a strategic business function accounting for the raison d'etre of construction companies", yet they acknowledge the significant gap in best practices in management between new-build and refurbishment sectors. In part, this may be related to capacity: refurbishment is generally carried out by smaller organisations, and since organisations larger than micro-scale companies have capacity to work across multiple sites -- logically -- larger organisations serving the new-build market ought to have better capacity to manage quality effectively. The domestic new-build sub-sector is been shown reliably to exhibit less formal and often less sophisticated management practices than other construction sectors (Chan & Räisänen 2009). Moreover, it has been argued reliably that the RMI sector – of which SWI retrofit is a part – follows inefficient management practices (Killip 2011).

The risks presented by poor installation and specification make clear that there is a need for industry to safeguard against it in all stages of delivery. The various dimensions of quality and the conventions of quality management and construction management will be discussed further in relation to the research findings.

4.4 Theories of knowledge exchange and vocational training

4.4.1 Vocational training and learning

4.4.1.1 A history of vocational training

The UK has a long history of apprenticeship training in the construction industry. By the 1960s, dissatisfaction with traditional apprenticeship structures had grown and complaints were registered that they were no longer meeting the needs of industry, that they held back evolving standards of working practice and integration of new technology, and did not seem to be serving the female population (Rudd et al. 2008).

Coupled with a cross-sector decline in British manufacturing and rising unemployment during the 1970s and 1980s, apprenticeship became increasingly unattractive. Added to this, waning power and membership of trade unions, weakening of workers' rights, and legislative changes successively led to diminishing appeal of traditional trades-based jobs (Macleod & Hughes 2006). Perhaps unsurprisingly, investment in vocational training dropped and cross-sectoral apprenticeship enrolment fell from 171,000 in 1968 to just 34,500 in 1990 (Macleod & Hughes 2006, p.8).

Throughout this time, many training and educational initiatives in the construction industry[28] became associated with social engineering and cut-rate labour. Over time they became discredited and critics argue this led to reduced social status of vocational training (Ryan & Unwin 2001; Finegold & Soskice 1988).

Perhaps in response to this, there was a move in the early 1980s to reform vocational qualifications. In 1986, the DeVille Report recommended the development of NVQs. In 1994 the Modern Apprenticeship programme was created which – rather than leading to Level 2 qualification as most government-backed programmes did – led to Level 3 qualification. Modern Apprenticeships and the NVQ framework were designed to assess practice in the workplace rather than technical knowledge or classroom learning.

The NVQ framework was conceived with several further aims: to ensure that apprentices had employed status from the beginning; to improve general access including for older

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[28] Initiatives include the Technical and Vocational Education Initiative (TVEI), Youth training, and the Certificate of Pre-Vocational Education (CPVE)

and unemployed adults; and to reduce required enrolment periods in apprenticeships by shifting emphasis toward meeting standards (Macleod & Hughes 2006, p.8). Steedman (2010, p.17) notes that apprentice pay as a percentage of skilled adult pay has remained low in construction and is nearly the lowest among major apprenticeship sectors – averaging just 48 per cent.

4.4.1.2 Contemporary apprenticeships and critiques

In recent decades, a substantial proportion of apprenticeship training has been facilitated by the Construction Industry Training Board (CITB), part of ConstructionSkills.[29] The CITB draws its funding from industry levies.[30] ConstructionSkills solicits input on training needs from industry and coordinates with training organisations who deliver training. As employers have a natural interest in how their levies are used, this system functions as a demand-driven structure. A publication by the Department for Education and Skills (2005) strengthened emphasis on 'demand-led' training policy and gave further priority to employers' for setting directions in training and accreditation while also reinforcing their role in providing training.[31]

Critiques of Level 2 construction apprenticeship programmes (which include SWI installer training) note that they fall short of the rigour found in continental Europe (Institute for Employment Research 2012, p.4). Richard (2012, pp.7–8) found "Continuous and time consuming assessment, driven by paper-based tests, accumulated 'evidence' and assessors with a vested interest in apprentices passing the test, demeans the apprentice's accomplishment… The final test and validation must be holistic, in that it seeks to test the full breadth of the relevant competencies not merely the incremental progression of the apprentice."

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[29] The CITB, the Construction Industry Council (CIC) and CITB-ConstructionSkills Northern Ireland collaborate as the Sector Skills Council for Construction, known as ConstructionSkills.

[30] The CITB was borne out of the construction Industry Training Board, which was established in 1964 under the Industrial Training Act. The Act (amended in 1982) mandates large construction employers to pay a levy to the CITB, which is used to provide a variety of services, including apprenticeship schemes and industry card schemes.

[31] Sector Skills Agreements were proposed, which provided a framework for employers to outline needs, employees to identify how they will work toward developing those needs, and training providers to agree with both parties how they will meet this demand. Also proposed were Skills Academies, which were collaborations between training colleges and workplace training providers.

In 2007, the Select Committee on Economic Affairs (House of Lords Select Committee on Economic Affairs 2007, p.5) argued that, "The UK has an excellent record in higher education but a poor record in providing skills for the rest of the population. The result is unnecessarily low productivity and low wages for many, to the detriment of the economy, as well as needless disaffection among the young…".

The committee added, "Many young people leave school without the basic functional literacy and numeracy required for apprenticeship… Problems also surround the apprenticeship programmes themselves… Apprenticeship schemes have suffered from too much emphasis on quantity over quality." It argued for again "renovating and expanding the existing apprenticeship system" while lamenting the failure of successive governments to reform training despite "a stream of policy initiatives".

Similarly, Richard (2012, p.4) argues that "Many of our younger learners have more to learn than an apprenticeship can encompass; the path they need to travel will be longer. They must learn the skills to be employable in the first instance." Richard suggests a potential need for "a period of pre-apprenticeship training and effort…".

Despite these calls, and the 2010 Specification of Apprenticeship Standards in England and the ASCL Act (2010) which aimed to improve the quality of apprenticeship programmes and set a minimum 12-month duration[32], the situation remains largely unchanged. In recent years public funding for apprenticeship and training has been restricted. The Comprehensive Spending Review conducted in 2010 led to a 25 per cent reduction in funding for Further Education and Skills between 2011/12 and 2014/15.

Richard (2012) argues that the Government ought to assume a greater role in funding, but also in controlling, the delivery of apprenticeship programmes.

[32] For apprentices over the age of 18, providers must ensure a 'minimum planned delivery' of "a period of learning and workplace practice... unless there is the accreditation of prior learning' (Skills Funding Agency, 2012, p. 29, as cited by Institute for Employment Research 2012, p.4).

4.4.2 Theory of learning and teaching

4.4.2.1 'Learning' and 'teaching' curricula

Legitimate peripheral participation (LPP) captures low-level learning in which an asymmetry exists between actors (Lave & Wenger 1991, p.40). As an apprentice works with a journeyman tradesperson, for instance, she is likely to learn skills or knowledge quite intentionally. LPP reflects the 'accidental' learning that occurs simply by coparticipation, even when learning is not an overt premise to the interaction between actors. Purely through being in proximity, habituation is inevitable. This is an important form of 'learning' in the context of SWI.

4.4.2.2 Reflective education and critical thinking

In 'Thinking in Education', Matthew Lipman argues that the Piagetian paradigm dominated American education until the late 1970s, and entered debate in Britain a decade later (2003, pp.38–40). The legacy of this outmoded understanding of child development, he argues, had a profound impact on education and limited the teaching of critical thinking to children at least until the very last years of schooling and tertiary education. He asserts that this continues today. Lipman (1989, p.7) explains that children are not encouraged to develop their own rationality and abilities to think critically. In an earlier essay, he laments "teaching students about critical thinking is about as unlikely to create a nation of critical thinkers as having students learn research results about bicycle riding is unlikely to create a nation of bicycle riders…".

Lipman proposes the benefits of reflective educational pedagogy over outmoded conventional hierarchical education paradigms. In a reflective pedagogy, knowledge is sited within the student – it is developed through processing and is often co-produced and the result of reflection and experience.

4.4.2.3 Knowledge exchange

Fryer and Fryer (2004, p.142) report data collected by the BRE that place human factors as central to failures in design and construction phases. These included "poor communication, inadequate information… inadequate checks and controls, lack of technical expertise and skills, [and] inadequate feedback…".

Hartenberger et al. (2013) argue that improvement in retrofitting industries is impeded by barriers such as poor information capture, communication, rivalry and hierarchal thinking. They suggest that medicine offers models of education. The parallels between construction and medicine are noteworthy: they are both atomised professions consisting of networks of specialisation, and both have traditions of apprenticeship, and inter-and intra-disciplinary learning and interaction (in construction, for instance, between surveyors, engineers, process technicians, architects and asset managers). They identify in medicine ideals of problem-based learning and 'closed practice-research-education-training' loops.

Unstructured knowledge flows

Bartsch et al. (2013) argue that the very nature of project-based work is an impedance to knowledge transfer. In their qualitative survey, which included 144 organizations in the German engineering industry, they find that intraorganisational social ties allow transference of learning about products, technologies, management strategies, as well as market conditions. Similarly, Dahl and Pedersen (2004) found that 'cross-boundary' informal networks among engineers in Danish communication firms were important to the diffusion of general and specialised knowledge in the context of the concentrated geographical area used in the research.

Collins and Evans (2008) present a "periodic table of expertise" and differentiate between popular (ubiquitous) levels of 'tacit' understanding, basic "beer mat knowledge", and more advanced proficiencies they delineate as interactional expertise (technical fluency and specialism) and types of "meta-expertise".

Szulanski (1996) identifies 'stickiness' in the transfer of knowledge and practice (in which he includes transfer of tacit knowledge). He argues that transference is impeded not simply in motivational factors, but in lack of absorptive and retentive capacities, ambiguity, and the nature of relationships between recipient and originator. Szulanski's work suggests that SWI quality should be improved by high quality programmes of apprenticeship and mentoring.

Organisational learning

Learning within organisations remains a challenge in many areas of construction. Approaches to capturing knowledge from projects have long been discussed (e.g. Latham 1994) yet remain underdeveloped (Tennant & Fernie 2013). This may be exacerbated by a history of low enrolment in higher education degrees (Dainty & Edwards 2003), which has implications for thought leadership. Techniques such as post-project reviews (debriefing participants after project completion), intranets used to capture and distribute knowledge, and ‘centres of excellence’ which centralise knowledge and expertise are not new (Winch 2002), but have remained underused (Carrillo, et al. 2013).

‘Managing’ tacit knowledge is recognised as highly difficult, and benefits from significant investment in structured approaches (Robinson et al. 2005). Organisational learning models such as shown by Bell et al. (2002) can be recognised in many areas of the UK construction industry (e.g. Tennant & Fernie 2013), but remain largely absent from the RMI sector. Organisational learning can be observed across networks, or CoPs (Wenger 1998). Very little study to date has examined the relevance of these findings to the SWI industry.

In their examination of organisational learning Tennant and Fernie (2013) revisit Bell et al.s’ (2002) model of organisational learning in their analysis of qualitative research in seven UK construction companies (two client bodies, two first-tier providers and three contractors). They document high frequencies of *economic* and *managerial* ‘schools of thought’ -- in which learning takes place through accidental discovery and accrued understanding. This occurs as a result of repetitive action and reaction (economic school) and higher order mechanisms of management-led actions, calculated intervention and formal knowledge transfer instruments (managerial school).

4.4.2.4 Models of knowledge exchange

Communities of inquiry

‘Community of inquiry’ was originally used to describe scientific practitioners who employed similar procedures in a shared pursuit of certain goals of discovery (Lipman 2003, p.20). Since then, the term has been applied to a diversity of settings in which a collective pursuit of learning or discovery is present. Seminal American pragmatists Charles Sanders Peirce and John Dewey developed the concept of ‘communities of inquiry’ in studying the process of knowledge discovery. Working in the latter half of the 19th Century, Peirce introduced the concept in the context of natural science discovery. Dewey applied the concept to his pioneering work in educational theory.

Peirce described how the evolution of science was the product of social processes and resulted from negotiations and interactions between actors. He rejected the conventional view of a linear and fixed rational progression, and argued that the evolution of knowledge was embedded in ‘communities of inquiry’. He argued that knowledge is – in essence – subjective; it is agreed and understood by a community and is the product of that community's shared processes of discovery. (Haskell 1977)

In 'How We Think', Dewey (2007), a student of Peirce, traced the origins of scientific inquiry to innate patterns of problem-solving behaviour. He argues that in early populations, solving problems would have been based on historical experiences of success and failure. When a previously-accepted 'truth' became challenged by experience, then alternate hypotheses were a natural outgrowth of the instinct to achieve alternate solutions or explanations.

Josiah Royce further adapted the concept in his exploration of interpretation, meaning-sharing, and meaning-creating in community. Since then, it has been employed in a wide variety of fields. (Lipman 2003, p.33)

In this research, analysis has drawn on awareness that 'understanding' can be viewed as a social enterprise and is dynamic. This has particular relevance to examining how understanding is created, and to recognising the distinction between knowledge and understanding. It is accepted that understanding is shared and is the product of collectively negotiated truths. This informs discussion of how evolution of understanding and transference of knowledge might occur.

Communities of practice

The 'communities of inquiry' concept has had far-reaching impacts in sociology, education, psychology and other fields. Rooted in this and in broader arguments by Peirce, Dewey and their contemporaries, is the work of Jean Lave and Etienne Wenger[33]. Lave and Wenger (1991) advanced the concept of a community of practice (CoP).[34]

CoPs, it is argued, offer great benefit by fostering interaction and engagement, shared purpose and knowledge exchange (Wenger 1998). This is the result of successful sharing of knowledge and improved understanding (i.e. shared internalisation of tacit knowledge), and leads to improved individual and organisational performances. CoPs

[33] Jean Lave and Etienne Wagner wrote 'Situated Learning'. In it, Lave, (a social anthropologist and theorist), and Wenger (a social theorist and educational theorist who trained in information and computer science), argue that learning should be located in social interaction and is best achieved through co-participation.

[34] CoPs in their most basic form are informal groups of people (often not co-located) who share a common profession or interest and exchange information and learn interactively as they face common problems or strive to improve practices.

increase the availability of social capital (Bourdieu 1991) among professional networks. Because they improve knowledge exchange, they offer the potential for improved innovation and problem solving as well as reduced barriers for new professionals. Lave and Wenger (1991, p.122) explain the role of CoPs and their potential for instilling a sense of belonging and motivation:

> The *person* has been correspondingly transformed into a practitioner, a newcomer becoming an old-timer, whose changing knowledge, skill, and discourse are part of a developing identity – in short, a member of a community of practice. This idea of identity/membership is strongly tied to a conception of motivation. If the person is both member of a community and agent of activity, the concept of the person closely links meaning and action in the world.

For Fischer (2013, p.203), who looks at 'cultures of participation' CoPs present a "danger of *group-think"* (Janis 1972): the boundaries of domain-specific ontologies and tools that are empowering to insiders are often barriers for outsiders and newcomers."

Analysis and discussion in this research have been informed by the concept of CoPs. The SWI milieu is interpreted as a CoP (or as an amalgamation of CoPs) and it is understood that learning takes place within networks. The study of those observed examines the presence and functionality of networks (and potential danger of groupthink).

Situated learning

Lave and Wenger (1991) rebuff the notion that learning is merely a *transmission* of knowledge, and propose instead that it entails interaction processes and co-participation (i.e. 'situated' learning and communication). They are interested in non-hierarchical learning and access for learners to participating roles and argue that learning is essentially a social process.

Lave and Wenger draw a clear distinction between 'situated learning' and apprenticeship, but acknowledge that "various forms of apprenticeship seemed to capture very well our interest in learning in situated ways – in the transformative possibilities of being and becoming complex, full cultural-historical participants in the world" (1991, p.32).[35]

[35] Lave and Wenger's work stemmed from research sited in craft apprenticeships among Liberian tailors but they describe as a coincidence that educational and cognitive research often terms situated learning through the metaphorical use of the word 'apprenticeship'.

Despite the potential for confusion (given that vocational training relies heavily on apprenticeships), situated learning is an important model in the analysis of knowledge exchange in SWI retrofitting. This thesis does not intend to engage in pedagogical critique of training in the SWI milieu; however it does examine successes and failures in training and knowledge exchange pathways. This examination benefits from Lave and Wenger's demarcation between hierarchical knowledge transmission and the contextualised and social process of learning.

4.5 Systems of professions

'Systems of professions' (Abbott 1988) explain how occupational groups comprehend their work and negotiate against others for power. In a system of professions, professional roles and groups form (conditionally and *pro tem*) by tacit or explicit identification and are understood to be exclusive holders of specific tasks and knowledge (i.e. form a 'jurisdiction'). Groups develop specialised language, associations (distinct or implied), codes of behaviour, formal training norms and controls on access and entry. With this, people outside of a jurisdiction become excluded. According to Abbott (1988), shared professional identity among groups offers distinct benefits including protection of trade and the right to practice, but also better knowledge and technology transfer and collective (often passive) goal setting and ability to achieve goals.

As an example, house painters identify themselves as distinct from interior designers and landscapers. They recognise in themselves, and are recognised exogenously for, shared technical ability, knowledge, responsibility, and cultural location (none of these are static). SWI installers exhibit – to greater or less degrees –group characteristics. This research has characterised the controls on access and entry to this group as weak; nonetheless, it is clear that installers exhibit some notable attributes of groups.

Extending the example, house painting and wallpaper hanging may be negotiated as distinct jurisdictions but may also appear in a shared jurisdiction. Professional groups 'compete' and are defined in their 'defence' of roles. The delineation of groups is understood in literature to be dynamic and to change over time in response to intra- and inter-group forces as well as social, economic and technological forces. In her doctoral thesis, Silva (2000) shows that historically, this has arisen in both formal and informal processes in different professions. Interpreting the systems of professions model in SWI, we see that installers have distinguished themselves from plasterers, and many who have migrated to SWI have done so in response to economic impetus. The technology of SWI itself has played a significant role in allowing a splintering of the 'wet trades' group.

Identity is often described as at partly rooted in technology and exclusive domain over new or existing technology. In their examination of professional identity in the medical profession, for instance, Korica and Molloy refer to "pioneers and visionaries who 'refresh' the profession by introducing and promoting new technologies" but also lead to 'clubs' and define 'outsiders' (2010, pp.2–3). They describe a process of gradual technology share (which they identify as rooted in technology pull) before a phase of normalisation arrives. They identify how new technology exerts tensions both at intra- and inter-professional levels.

Commenting on emerging professional roles in low carbon building and refurbishment, Bresnen (2013, p.736) explains that some have used Abbott's work to understand how "forces acting upon the activities and knowledge base of building professions… have served to erode the status and influence of particular professional groups…".

Professionalisation is not intractable. Abbott (1988) argues that work itself, not the structuration of a profession will sustain a systemisation of professions. He (2014, p.18) notes that sociological theorists have shown that "deprofessionalization and proletarianization" can undo "unidirectionality".

Equally, professionalisation may in fact lead into self-destructiveness if disfavour in public perception sets in (e.g. electrotherapists, psychological mediums, and railway surgeons) (Abbott 1988, p.18). Likewise, a profession might fall victim to de-professionalisation if it does not protect its own standards of qualification and certification and ensure that they are able to adequately guarantee quality in delivery. Finally, a group that cannot lay claim to a legitimate specialisation may become prone to what Abbott (1988, p.51) describes as "jurisdiction incursion" from other professions. Abbott (1988, p.124) holds that jurisdiction must be continually justified, and is demand-driven, asserting, "Client differentiation gains when demand for professional services exceeds capacity and shrinks when it falls".

4.5.1 Middle actors

Nösperger, et al. (2011) draw on the system of professions approach in their examination of "middle agents" in the construction industry (Section 3.2.2.1). They identify that Abbott's (1988) work is focused primarily on the "meso or systems level" which is concerned with relationships between professions (although he also outlines higher and lower levels: at the micro level negotiation occurs internally, and at the macro level shaping forces are exerted on systems from outside the professions). The authors' concern is with the emergence of new professions (i.e. groups), which is an area they argue Abbott's work does not offer a robust engagement with. In the context of sustainability and climate change, they argue that new competencies, knowledge and opportunities combine to give rise to new professions (Figure 15).[36]

Due to copyright restrictions, content has been removed by the author of this thesis following examination.

Figure 15: "Roles and competencies for the integration of low carbon refurbishment into a system of professions" (Nösperger, Killip, & Janda, 2011, p. 1368)

[36] Using essentially the same representation as is shown in Figure 15, Janda and Killip (2013, p.43) explain “gaps appear at the intersections of the professions and competencies, indicating spaces and imperfections in the current system. To this system, low carbon refurbishment is added as a possible new profession or jurisdiction, or both.”

4.6 Summary

The wide range of literature reviewed in this chapter provides a broad foundation for understanding the findings and analysis presented in this thesis. In the next two chapters the research methodology and methods are presented, this is then followed by presentation of results, analysis and discussion.

5 Research framework: approach and methods

5.1 Overview

This research has developed and addressed a range of questions about the delivery of SWI. Correspondingly, it delineates factors that characterise, drive, impede and underlie the success and failure of observed retrofits. This work has adopted an inductive approach because – most fundamentally – no extant set of hypotheses was available on which to base more deductive or positivist inquiry.

Research strategy and analytical frameworks are informed by previous social, socio-technical and organisational researchers, whose methods and methodological strategies are fused to produce an appropriate and robust approach. Key aspects of these are reviewed in this chapter.

The chapter concludes with a description of the methods employed and the influences that have shaped the research design.

5.2 Ontological and epistemological topics in social research

To develop an understanding of the perspectives and experiences of others (whether from within one's 'culture' or outside it) is inherently a messy and difficult task. One is obligated to confront a variety of epistemological and ontological issues almost guaranteed to present logistical and practical challenges.

Yberna (2009, p.349) writes, "The world that researchers study does not arrive pre-labelled and pre-theorized." Researchers must access and assemble meaning and develop understanding without unwittingly overstepping the boundaries of what can be 'known' or deduced.

5.2.1 Interpretivism

Interpretivism questions the notion that humans are akin to knowable objects in natural science, and instead positions humans as elements within social constructs. It argues that to understand human actions, we must access the perspectives that are held by the individuals and groups we study rather than building assumptions based on simple observation. In this research, methods were developed in response to this understanding.

Max Weber recognised knowledge as an interpretation of the world. The implication, then, is that social researchers can only understand the rational actions of others (as opposed to those which are irrational, affective or traditional) – and therefore should limit study to instrumental action (action made rationally in pursuit of an end). *Verstehen* connotes the interpretive understanding of rational action in others or in groups. Weber argued that as observers, we can only make sense of actions by interpreting why the actor did something and what the action meant for her. Importantly, Interpretivists assert that in light of the complexity of social realities, we cannot establish cause and effect relationships in observed phenomena, but rather can only explain correlations and identify influential (or non-influential) factors. (O'Reilly 2004)

The development of the research approach has intended to foster closeness with participants in order to study behaviours and actions within social contexts. It has been concerned not solely with actions, but with developing understandings of actions.

5.2.2 Phenomenology

Phenomenological critiques arose in the 1960s and 1970s and suggested that researchers study and understand participants through a rational process of typification and classification. Alfred Schutz (1972) understood that as humans, we make sense of received stimuli through a process of categorisation and association. By extension, phenomenology asserts that social interaction is governed in much the same way; we establish types or classifications of people and ascribe behaviours to these types. These distinctions, it argues, then form our expectations of our social world and indeed form our actions toward and interactions with other actors.

This sort of structuration appears in ensuing interpretivist arguments, including symbolic interactionism (in which shared meanings are constructed through interactions). Idealism – which owes much to the contributions of Peter Winch – posits that realities are defined by languages, predispositions and world views (Dallmayr 2012). It argues that collective conceptualisation of reality shapes the individual's experience of his world. In order, then, for an outsider to understand a culture, he must first understand its societal norms, rules, language, and signifiers. This contributes significantly to Actor Network Theory (ANT) and its proposition of how patterns of procedures and interactions are perpetuated.

The approach to this project has been informed by these arguments and has strived to achieve immersion in the SWI milieu in order to create richer understandings and development of questions which were 'closer' to the realities experienced by participants.

5.2.3 Subjectivity and reflexivity

The "truth" about phenomena and constructs can be a tempting illusion in social research. The impact of how a researcher interprets and reports observations – the insertion of value judgements and researcher balance -- has been debated for many years. To some, subjectivity is even a strength of qualitative research. Daytner (2006, p.5) explains that it can be valued "as a useful and personal quality of a researcher, resulting in unique insights into the understanding of a phenomenon". Peshkin (1988) meanwhile urges great caution against subjectivity and a formal approach to reporting it. Rivas (2012, p.367) uses more lenient language and accepts that "theoretical sensitivity" or the sensitivity of a researcher to "concepts, meanings and relationships within the data, [which come] largely from professional and personal experience" are inherent and should merely be "considered" by the researcher.

In this project, minimisation of subjectivity is recognised as an appropriate objective but impossible to achieve comprehensively. Coding is reported in relation to the themes that emerged and in many instances observation is reported directly in the text. This is an attempt to allow the reader to understand the origins of the interpretations that have been made.

It should be recognised, however, that ethnographic approaches and participant observation are intrinsically reflexive processes. In contrast to traditional forms of social science, 'designing out' the researcher is not possible (and perhaps disadvantageous).

The researcher is present 'in the scene' of the research. Simply by virtue of being there, she exerts a shaping force on the behaviours of those around her. To use an anachronistic term, 'going native' is an attempt to mitigate this 'otherness' of the observer-researcher. This may not ever be fully possible and certainly in the confines of a relatively short research project such as is reported here, to truly go native is not fully possible.

The researcher inescapably draws his frame of reference from his own domain. Even with the best of intentions to avoid doing so, questions and the interpretation of answers will be distorted by this frame of reference. This remains an unsolvable issue in ethnography. Writing fifty years ago, Black and Metzger (1965, p.144) described this challenge:

> It could be said of ethnography that until you know the question that someone in the culture is responding to you can't know many things about the response. Yet the ethnographer is greeted, in the field, with an array of *responses*. He needs to know what question people are *answering* in their every act. He needs to know which questions are being taken for granted because they are what "everybody knows" without thinking… Thus the task of

> the ethnographer is to discover questions that seek the relationships among entities that are conceptionally meaningful to the people under investigation.

Analysis is a search for patterns, whether in observations of interactions (social context) or more nebulously in cultural constructs. In the former, behaviour and artefacts can be observed and patterns delineated. In the latter, these are placed within a more complex and less definable context which includes knowledge, shared understanding, shared (and divergent) meanings, and relevance to people, places, objects, or experiences which may not be immediately accessible to the researcher. The search for patterns is a human instinct, but it must be tempered by awareness of one's frame of reference and the potential for distortion.

The same applies as the researcher captures language and events in the field and infers from these both meaning and translation into his own domain. There is a tendency to inadvertently project meaning and theoretical grounding as researchers; in this context Floersch (2004) argues that ethnographic and participant observation facilitate "knowledge-in-action" (cf. technical-rational knowledge).

Adding to the challenge, tacit meanings which are formed without recordable language leave the researcher with the task of recording (or ignoring) this information. Moreover, different members may use different ways of communicating (explicitly or tacitly) related messages. In all of these moments, the researcher relies on introspection and awareness of reflexivity in order to remain 'close'.

Closeness affords the researcher with opportunity to deepen her understanding of -- as described above by Black and Metzger (1965, p.144) – "the relationships among entities that are conceptionally meaningful to the people under investigation." Nevertheless, the participant observer is very often *inside* the scene and cannot (and arguably should not) claim objectivity while studying the phenomena around him/her. Intrinsic to inductive social research is the selection of lines of inquiry, the disregarding of other lines and the framing of analysis. This may occur on a continuum of conscious or subconscious decision-making.

Wherever possible, the limitations of reflexivity have been recognised in this research and, throughout data collection, relevant caution has been exercised.

5.2.4 Tacit and explicit culture

Social structure and cultural influence in the research setting may be explicit and accessible to the researcher, but conversely might merely be implied. In a construction research setting, health and safety signage would be an obvious example of explicitly apparent culture; the signage would readily communicate several aspects of culture. Other clues would not be so apparent. For instance, it may be observed that construction workers often do not use personal protective equipment (PPE), and they may be recorded complaining that PPE restricts movement, is uncomfortable, or reduces field of vision. It might also be noted that workers routinely use PPE whenever site supervisors are present, implying hierarchical power relationships and norming. This is an example of a tacit cultural force that might be recorded.

In the above example, the observation might also lead to a logical conclusion that the site supervisor has a motivation to ensure compliance with PPE regulation, while the workers seek to avoid conflict with or secure favour from their supervisors. There is of course here a risk that without caution, the influence of reflexivity might lead one to make a false assumption. More appropriately, the correlation between events could be understood as a theme, and in time could be investigated more deeply or placed in the context of other observations or recordings.

Observation of tacit cultural forces is an essential element of ethnographic research and this project relies on assessing them alongside explicit signs. The development of research methods described in the following subsections was closely informed by a desire to avoid the pitfalls of misinterpretation which would be endangered by 'shallow' observation of the scene. These methods were selected to foster a deeper comprehension of research settings (as far as practicable within the project confines), and to avoid removed observation that might fail to capture nuanced understandings.

5.3 Inductive research

This research has used qualitative and ethnographic methods and has been informed by several traditions of inductive theory-generating research. The complexity of 'knowing' has been recognised from the outset and the research has been guided by various debates and practices in developing and applying a research method. The inductive and interrogative traditions and methods drawn on include:

- Grounded Theory;
- Progressive Focusing;
- Ethnography;
- Participant observation;
- Interviewing; and
- Non-participant observation.

The research largely drew on unstructured interviewing in its early stages, and subsequently drew on unstructured interviewing, non-participant observation, and retrofit site inspection. Later research closely followed traditions of participant observation. Other traditions listed here have informed -- but do not neatly correlate to -- the research design. In the case of ethnography, this project could be seen as an ethnographic piece of research, but it does not follow the traditions of writing (e.g. thick description) that are typical of ethnography.

5.3.1 Grounded Theory

Glaser and Strauss (1966; 1967) introduced concepts of constant comparative method and Grounded Theory (GT) at a time of great change and ontological debate in social research. An evolution of thinking about science was underway and in social research circles many began to argue that researchers should not be seen as detached and removed observers pretending to be divorced from the world they recorded and studied. Researchers were increasingly recognising their own mark in research and debates challenged almost any claim of theoretical validity.

GT emerged as an approach to developing understanding. It provided an alternative to deductive research, and outlined a method of inductive theory-building. Glaser and

Strauss were, as Pratt (2012, p.4) describes "… seeking a method to give assurance and security about method to practitioners in the social sciences."

Since then, GT has enjoyed great popularity but become a topic of endless debate. Discourse has debated (and muddied) the legitimacy of bipolar distinctions between inductive theory-building approaches and deductive approaches and positivist research where were asserted by GT practitioners. Further arguments have debated the very tenability of theory 'discovery' and asserted that the research 'world' is, fundamentally, socially constructed (Orton 1997).

Almost as soon as GT gained popularity, schisms emerged in interpretation and arguments debated if it was an untenable approach to work, or if it was simply misread by critics. Many argued that there was problematic divergence between "theoretical sensitivity" and "emergence" (Kelle 2005). As postmodern critiques emerged, GT began to be criticised as 'theory-heavy', lacking reflexivity (Martin 2006), prone to oversimplification, and tacitly encouraging analysis which could (ironically) become distanced from data.

Early on, Glaser (1978) attempted to address critiques by differentiating between substantive and theoretical coding and providing a loose framework within which diverse concepts could be related to data. Perhaps exacerbating postmodernist critics, Strauss (1987), and Corbin and Strauss (1990), attempted to resolve criticisms of ambiguity and complexity by promoting axial coding. In constraining coding to these axes, they immediately constrained analysis paradigmatically, even if only skeletally. This can be seen as a risk of "the technical tail beginning to wag the theoretical dog" (Melia 1996, p.376, as cited by Mills, et al. 2006, p. 27).

Glaser and Strauss are easily seen as polarised in arguments about approaches to data analysis. Walker and Myrick (2006, pp.557–558) describe this polarity by assigning Glaser as the artist and Strauss as the scientist, referencing Strauss and Corbin's words that, "Analysis is the interplay between researchers and data. It is both science and art" (1998, p.13). This may be an incomplete analysis. Mills et al. (2006, p. 2) place interpretations of GT on a 'methodological spiral' rather than along a polar delineation. They place constructivist GT as offering "an explication of the field of what can be known" and argue that it repositions "the researcher as the author of a reconstruction of experience and meaning."

In the evolution of debate about GT, many have aligned themselves with certain interpretations and found at least partial foundation and substantiation for their own approaches to research. Charmez (2008) distinguishes between social constructionist and objectivist GT.[37] She argues that (2008, p.398):

> How, when, and to what extent grounded theorists invoke social constructionist premises depends on their epistemological stance and approach to research practice… a social constructionist approach encourages *innovation* [emphasis in original]; researchers can develop new understandings and novel theoretical interpretations of studied life. The value of social constructionism for GT studies has only begun to be mined.

This research uses an approach informed by many aspects of GT, particularly in its Glaserian delineation of 'method'. GT, when seen as a tradition which recognises social constructionist debate and responds by offering a (loose) framework of interrogative and iterative data collection and theory-building, is useful in inductive research. As an example of how to approach research and collected data (and the debates which any approach might produce), this tradition is deeply informative. GT cannot be read without engaging with critiques of constructionism and relativism and these are hugely important to any social research. At the point that it becomes rigid and inflexible (Mills et al. 2006, p.27), GT risks constraining the researcher -- and so constraining research and artificially distancing the researcher from his or her data.

To be sure, the many interpretations and debates surrounding GT require cautious ontological consideration. Engaging with critiques of GT requires us to constantly account for our decisions and actions as researchers (Guba & Lincoln 1994).

This thesis draws on the traditions of inductive inquiry, of which GT is an important part. It does this while maintaining a pragmatic observance of the many critiques and debates surrounding GT. The complexities of 'knowing' and of situating discovery have been borne in mind at each stage of data collection. Emerging from the debates around GT is space for iterative research which recognises that inductive theory must be grounded;

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[37] Charmez explains (2008, p.397) that a social constructionist approach allows the researcher to deal with "*what* [emphasis in original] people construct and *how* [emphasis in original] this social construction process unfolds." Objectivist GT builds theory to explain observed phenomena, but this elucidation is "separated and abstracted from the specific research site and process" (2008, p.398).

even if developing this theory need not be aligned with prescriptive approaches or methodological protocol.

5.3.2 Ethnography

Ethnography is an approach to the study of human lives which recognises the importance of actions, artefacts and environs. Therefore, ethnography is fundamentally the study of the interrelationships between these and can be understood as an approach to developing nuanced understandings of human behaviour within a given context.

Walsh asserts that ethnography diverges from positivist, naturalist approaches to social research (2012, p.248) in at least two ways:

> First, ethnographers study people in their natural settings… seeking to document that world in terms of the meanings and behaviour of the people in it. It [examines] socio-cultural construction. Second, it does not follow the sequence of deductive theory testing because it is in the process of research itself that research problems come to be formulated and studied. Often these prove to be different from the problems that the ethnographer had initially intended to study.

Bronislaw Malinowski, (b. 1884), is widely considered to be the first to employ a systematic approach to anthropological fieldwork and participant observation.[38] An important contribution of his work (though not a novel one) was locating study in the field instead of basing study on collected evidence.[39] Malinowski's contributions came at a time when empiricism was the dominant mode of developing knowledge. His work, and that by Margaret Mead and others, contains both the siting in 'native' settings and the concern with observation of everyday events, interactions and objects that now commonly define ethnographical research.

[38] The origins of ethnology and ethnography are somewhat subjectively defined. Herodotus, the 5th Century BCE Greek historian certainly utilised ethnological methods. Ethnography is often traced to the more recent work of Gerhard Friedrich Müller in the 18th Century Great Northern Expedition.

39 Prior to the work of Malinowski and his contemporaries, anthropological research was essentially the study of artefacts and information brought back by 'amateurs' (e.g. missionaries and colonial administrators) to develop insight into cultures and peoples. Although others were engaging in field study at the same time (early 20th Century), Malinowski's focus on methodology and collection methods were largely unprecedented. (O'Reilly 2004)

Ingold (2014, p.388) describes ethnography as “education by attention”:

> Simply put: in the conduct of our research, we meet people. We talk with them, we ask them questions, we listen to their stories and we watch what they do. In so far as we are deemed competent and capable, we join in... You tell people that you have come to learn from them. You are perhaps hoping that they will teach you some of their practical skills, or that they will explain what they think about things. You try very hard to remember what you have observed, or what people have told you, and lest you forget, you write it all down in fieldnotes as soon as the opportunity arises… [W]hat we could call “ethnographicness” is not intrinsic to the encounters themselves; it is rather a judgment that is cast upon them through a retrospective conversion of the learning, remembering and note-taking which they call forth into pretexts for something else altogether… It is this that turns your experience, your memory and your notes into material— sometimes spun quasi-scientifically as “data”— upon which you subsequently hope to draw in the project of offering an account.

O’Reilly (2004, p.3) organises her work on ethnographic methods around a list of critical minimum markers – she asserts that ethnography is:

- Iterative-inductive research (that evolves in design through the study), drawing on
- a family of methods,
- involving direct and sustained contact with human agents
- within the context of their daily lives (and cultures);
- watching what happens, listening to what is said, asking questions.

This research has a great deal in common with ethnography as O’Reilly describes it here. But she goes on to describe other aspects which do not appear fully in this work (2004, p.3), explaining that ethnography:

- produces a richly written account
- respects the irreducibility of human experience,
- acknowledges the role of theory
- and the researcher’s own role,
- and views humans as part object/part subject.

Like some ethnographic research that also differs from O’Reilly’s first point, the written account of research here is not intended to offer ‘thick description’. Rather it focuses on extracting the themes of findings and discussing their technical, social and political contexts. The expository nature of this document is intended to communicate analyses clearly to the reader, which might not have been achieved successfully through the stylistic convention typical of many written ethnographies. This style is not exceptional and has been adopted to varying degrees by writers of organisational and workplace ethnographies.

Ingold laments (2014, p.383) "equivocation… scholarly obscurantism, and… the conceit that turns the project of anthropology into the study of its own ways of working." This project benefits from the closeness afforded by ethnographic methods (Section 5.2) -- and acknowledges the fundamental limitations of the method in 'irreducibility of human experience' (O'Reilly 2004) and subjectivity -- but does not follow closely in ethnographic traditions.

Although no instances of ethnographic methods used to study SWI have been found in this research, the methods have been used in other contexts of built environment research. Thiel, (2007; 2013) and Sage (2013), for instance have examined topics of social class, gender and ethnicity. Pink, Tutt, Dainty and Gibb (2010; Tutt et al. 2013) have worked – often in collaboration – to examine issues of knowledge transfer, recruitment and skills acquisition, site practices, and socio-economic dynamics in construction.

5.3.2.1 Process

Ethnography demands a balancing act of roles between onlooker and member. Yberna et al. (2009, p.348) explain "the ethnographer is… cast in two roles simultaneously: situational participant and observing researcher". The method employed in this research is closely aligned to ethnographic traditions in this respect.

Ethnographers use and often describe a variation of focus in their observation and analysis (O'Reilly 2004). When studying a setting, in some situations, a narrow focus may be maintained on a specific task or interaction. Alternatively, observation or analysis may become much broader and aim to capture a totality of events or dynamics. Meanwhile, it may become appropriate to compare a number of instances of similar activities or situations. There are of course no neat distinctions in how an ethnographer might study her scene. This variation is typical of this research, which examines at a range of scales simultaneously.

Many ethnographers describe their research similarly to Spradley's (1980, pp.28–35) description of an iterative 'research cycle'. Spradley details how, upon selecting a project, the ethnographer will define her scope and begin to ask 'ethnographic questions'. This begins a process of collecting data, recording and analysing the data, and developing new questions. Others argue that it is better described as a process without distinct stages, in which research questions, data collection and analysis are constantly influencing each other and research design evolves iteratively as data collection is guided by emergent theory (Walsh 2012).

What all explanations have in common is that – in contrast to many other forms of social research which are concerned with answering questions -- ethnography is likely to pose new questions as readily as it answers them. It almost certainly results in discovering new questions and leaving many open ones. This is certainly reflected in this research project.

5.3.2.2 Scope

A central tension exists in literature on ethnography methods between 'surface' and 'in-depth' scope (Fetterman 1998; Marcus 1995; Hannerz 2003; Malinowski 2012). Many insist that ethnography necessitates prolonged and deep involvement in the research environment –- conducted over the course of many months or even years. In surface investigations, the focus is on delineating the phenomena which appear in a setting. Conversely, in-depth approaches seek to understand cultural meanings and how participants understand them.

Many argue that in-depth ethnographic research cannot be achieved except in a limited scope of settings and domains. This might be compared to the use of different lenses on a camera, through which different levels of detail, depth and breadth of image can be captured.

Spradley (1980) draws a distinction between 'micro-ethnography' and 'macro-ethnography'. He draws a continuum of research scope in which a range of size and complexity of topics can be studied. Moving from the micro to the macro scale, the focus shifts from a single social situation, to multiple social situations, then to the levels of single/multiple institution, single/multiple community and finally complex society.

These dichotomies are perhaps exaggerated. Rather than selecting one extreme, an alignment in one moment of research or another can be made instinctively. This research is more closely aligned to 'surface' and 'macro' ethnography as described here. It maintains a broad focus and is more interested in interpersonal and inter-organisational complexities than in probing how individuals behave or experience specific events. In reality, the distinctions between surface and in-depth ethnography blur easily.

5.3.2.3 Investigative ethnography

The term 'investigative ethnography' might be borrowed to describe this work. This term is not widely used in academic work[40] and is suggested here not to describe ethnography conducted for journalistic purposes but to acknowledge that the application of methods here is somewhat different from conventional ethnography. The term reflects the research aim of identifying and answering specific research questions rather than an aim of pursuing open-ended anthropological enquiry or examination of particular cultural phenomena. To the extent that the methodology overlaps with ethnographic traditions, it is for practical advantage and not that it is directly following specific conventions.

5.3.3 Participant observation

Participant observation lies at the foundation of ethnography and cultural anthropology.[41] Although this research project does not neatly conform to either research tradition, participant observation forms an integral part of its methods.

There is no universally agreed-upon definition of participant observation, and researchers' uses of the term vary. Writing over fifty years ago, Becker (1958, p.652) described participant observation in attractively simple terms:

> The participant observer gathers data by participating in the daily life of the group or organization he studies. He watches the people he is studying to see what situations they ordinarily meet and how they behave in them. He enters into conversation with some or all of the participants in these situations and discovers their interpretations of the events he has observed.

He goes on to describe the messiness which a researcher must confront in iterative analysis and investigation: negotiating questions of the credibility of informants; assessing potential for interpretive fallacy; and the potential for 'observer effect'. Becker's definition and the difficulties he outlined remain broadly relevant today.

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[40] A search for the term on the Google Scholar search engine returned just nine hits. No hits were returned on the Web of Science, British Humanities Index, or the Sociological Abstracts databases.

[41] Malinowski is commonly cited as pioneering the use of participant observation in ethnographic fieldwork. He famously studied the Trobriand Island population (near New Guinea) between 1915 and 1918. It was in reference to this period that Malinowski argued that an observer's summary of a society's rules and frameworks needed to be compared to observations of actual behaviour and to texts and statements made by 'the natives' in their own vernacular. (Urry 1993, pp.33–34)

Becker (1958, p.659) engaged with post-structuralist (i.e. functionalist) argument discussing the “knotty problem of how to present conclusions and the evidence for them”. The task of designing a descriptive model of the settings of participant observation data – the various “systems” which make sense of it -- is fundamental to the research process. Seen another way, this is interpretation of structure which is inherent in data (Reed 2012, pp.28–29). Balancing the act of interpreting with remaining ‘scientific’ (presenting evidence and forming and communicating analyses) is as “knotty” today it was in Becker’s time.

Writers commenting on observation methods routinely acknowledge that researchers’ involvement and interaction falls on a continuum of intensity and ‘closeness’ (Spradley 1980).

Participant observation is particularly valuable as a mechanism for accessing research milieux and developing multidimensional understandings. Dewalt and Dewalt (2002, p.13) assert that participant observation “encourages the continual reassessment of initial research questions and hypotheses, and facilitates the development of new hypotheses and questions as new insights occur as a result of increasing familiarity with the context”.

Participant observation forms a key component of this research for several reasons. It offers rich familiarity and ‘granularity’ from prolonged engagement and contact. This is ideally suited to generating knowledge of topics which have little or no published research, and to generating new understandings and questions. It also enables – using the earlier metaphor – the use of a variety of camera lenses with which to capture both the details and events which might be missed by other research methods, and in this way develops holistic understandings. It places the researcher as both an ‘insider’ and an ‘outsider’. It enables access that might otherwise be unavailable. The identity as ‘outsider’ is gradually supplanted (perhaps not fully) in the perceptions of participants as well as in self-perception; the researcher begins to observe and experience ‘inside’ reality.

Of course participant observation cannot provide objective knowledge. The act of interpretation Becker struggled with remains pertinent. This research has been conducted in full recognition of reflexivity and of the perils of overstepping in drawing conclusions. The method remains, however, valuable in developing new insight and questions.

5.3.4 Validity and verification

It was recognised from the outset of this project that the questions the research addresses were essentially qualitative in nature and as in any qualitative work, there were intrinsic epistemological uncertainties. The ability of qualitative research to portray reliably the true nature of phenomena or subjects is a central critique of qualitative research.

In this project, this is compounded by a dearth of similar published research. Assessing findings without previous directly related work to triangulate against makes validity and verification elusive aims. While it has been necessary to accept certain limitations inherent in the approach, these have not negated the value of findings. As would be expected, the application of methods and the analyses reported in this thesis have been closely informed by the conventions of rigorous social research described in this section.

5.3.4.1 Inter-rater reliability

We reasonably expect that two laboratory scientists can replicate results between duplicate sets of analyses. Qualitative research is often subjected to the same expectations of reliability. While this may on first approach seem logical, it is not always possible to achieve neat repeatability between social researchers.

Inter-rater reliability is a concept borrowed from quantitative research to apply to qualitative contexts, particularly with reference to the analysis of data through coding. It implies that the same data collected by different researchers should give rise to similar codes, and through frequency analysis, should produce nearly identical results. This is not necessarily a realistic (or desirable) outcome. As Spencer et al. argue, the objective of a researcher ought to be producing a meaningful analysis, not necessarily a foreseeable and repeatable one (2013, p.278):

> …for qualitative analytic approaches where labelling is done to manage data rather than to facilitate enumeration, there is not a 'right' or 'wrong' way of labelling the data…. the objective is to produce a meaningful account of the phenomenon that addresses key aspects of the research question, and to produce this account in a systematic and transparent way so that the reader can see how concepts, themes or categories were developed.

The objective in this thesis is that the reader will understand how the analysis has been reached, even if other researchers might have identified different themes or emphasised other questions from the same data.

5.3.4.2 Triangulation

Triangulation provides a means of checking the findings of research or improving the reliability of conclusions or interpretations. Denzin (2006) describes four types of triangulation: source; analyst/investigator; theory; and methodological. Denzin argues that understanding can be broadened, and results and analyses can (to an extent) be validated through triangulation by drawing on more than one data source or research site, or by interrogating analysis against alternate theory or against results obtained using alternate methods of data collection.

Hannerz (2012, p.402) discusses an additional form, labelled site triangulation. This is distinguished from 'multilocal', or multisite ethnography – which studies "translocal linkages". Hannerz argues that site triangulation is "different from a mere comparative study of localities", as it is concerned with relationships *between* as well as *within* sites.

Developing comparisons between multiple sources, investigators, theories, methods, or sites, creates robustness and can contribute recognising thematic saturation. Robust comparisons need not rely on divergent research methods, but can simply be based on moving between complementary modes of data collection (Daytner 2006).

Although this research draws on only investigator's work, it uses multiple sites, sources, and qualitative methods and examines results in the context of several bodies of theory.

5.3.4.3 Adequate engagement

Writers on qualitative methods generally espouse the importance of repeated observations of the same finding (Denzin 2006; Guba & Lincoln 1994).

There are of course no prescriptions for adequate engagement; the researcher must just make a determination based on judgement. Consensus in literature forms around the notion that data collection can safely cease when the potential for distortion from the researcher or participants appears to have abated, saturation has appeared, and complete access to a population, culture, or context has been gained (i.e. the study focus has been adequately accessed).

5.3.4.4 Engaging contrary interpretations

A responsible researcher will continually probe for disconfirming data to challenge her emerging theory. Similarly, she will consider and reconsider interpretations throughout the research process. These actions form part of the constant internal critique important to robust data collection and iterative analysis. Reporting her research usefully does not compel the author to discuss every abandoned interpretation or permutation of the data (Eisner 1991, p.111).

Engaging contrary interpretations is understood as a basic and constituent part of the intellectual process of inductive research.

5.4 Summary

The contexts of research theory provided here outline the approach to studying the SWI topic. This approach has balanced a desire to get 'close' to participants and the constructs in which exist, with a caution and scepticism about what is 'knowable' within the practical constraints of time and resources associated with this research project.

The traditions of inductive research have directly informed the development of research methods, which has been described in this chapter. The next chapter explains the application of these methods and the approach to analysis.

6 Application of research methods and approach to analysis

6.1 Overview

The application of the methods and the traditions and conventions that have informed this are described in this chapter. It outlines the setting, participants, and approach to recruitment, before describing analytical tools, and the considerations of ethical issues made during research. It then describes the structure of field research and the application of methods, which is followed by a list of participants cited in this thesis. Finally, the section concludes with an explanation of the approach to analysis of findings.

6.2 Setting and participants

At the outset, the impossibility of developing definitive knowledge relevant to all retrofitting has been recognised. It has also been accepted that capturing a very broad range of retrofit settings or research sites in meaningful detail would be unachievable. Equally, to attempt to limit the scope of research to an intensive study of a single setting or subject would undercut the ambition to offer theoretical explanations with potential relevance to the wider context of SWI retrofitting.

It was logical, therefore, to seek a compromise between a very broad perspective and an in-depth and focused enquiry. To develop meaningful work, but ensure sound analysis, this work is situated between these extremes. It takes place within a relatively small but varied subset of the wider SWI industry and landscape.

By working across a variety of sites and settings, this work offers a value which is three-fold: first, it serves to document and analyse the reasonably broad (if limited) cross-section which it captures; second, it offers site triangulation; finally, it offers to future researchers and readers the potential for drawing correlations and contrasts to a variety of settings. This research contributes a form of instrumental (c.f. intrinsic) case study (Stake 2009) by presenting insight from a range of settings. By drawing on varied settings, it broadens the base of gathered evidence and highlights congruency and dissimilarity between sites. This approach was selected in response to the breadth and dispersion that characterise the SWI milieu. As research questions unfolded, enquiry drew on a variety of methods across a number of sites (in part as a means of obtaining site and source triangulation).

Observation was limited to the number of actors and sites that could practically be included. Research captured roughly 100 experts and professionals and 1,000 in-process or newly-completed retrofits. This, however, occurred in varying degrees of duration and intensity. Between one-half and two-thirds of participants were observed or otherwise interacted with over the course of one or more days; between one-third and one-half for two weeks or longer, and approximately one-quarter for two months or longer. In some cases, interaction was limited to short conversation (i.e. between five and 15 minutes) or site inspection (i.e. several minutes). These shorter interactions and observations (not included in the above numbers) may have contributed to ‘saturation’ in analysis but do not substantively contribute to conclusions.

Research was conducted through three phases, which are described below in Section 6.6. Professionals and institutions across central and southern England and southern Wales were included in the first two phases of research. The extended study made in the third phase of research was sited in a leading SWI installation company which works across England and Wales. The vast majority of observation was made in area-based retrofit projects through shadowing and conversing with participants.

6.3 Recruitment, access and informed consent

Participants were recruited from several distinct professional communities across a range of geographic areas. Early research deliberately sought out experts in a variety of disciplines to provide a baseline insight into the research landscape. Selection of these professionals was based on professional reputation, job role and employer, and perceived breadth or depth of expertise relevant to the research questions.

During further research, which evolved iteratively, recruitment took place in response to a combination of factors. Chief among these was the suitability of potential recruits or organisations to address the various questions unique to each point in the progression of research. There was also an element of 'snowballing' in which participants directly or indirectly introduced or facilitated access to new recruits. Participants were also selected based on geographical proximity (this limitation was avoided as far as practicable). Generally, participants were not selected to serve as representative of a wider population; however participants who could reasonably assumed during the course of research to be 'outliers' in the general research landscape (for instance who worked in atypical projects or served niche markets) were typically not included.

Naturally, selection was impacted by the willingness of recruits to participate. In several cases, despite 'gatekeepers' being willing to provide access, others in their organisations who were relied on to coordinate daily arrangements routinely failed to assist (none explicitly expressed unwillingness to participate). In these cases participation in the research was not possible; this was in all instances only determined after sustained attempts to retain access.

Gaining and sustaining meaningful access, consistent and extensive enough to be valuable to the research, was a considerable challenge. It required negotiating a range of often subtle yet significant obstacles and at times navigating delicate socio-cultural situations. There were, as in nearly any social research project, everyday hurdles to overcome such as scheduling, gaining formal and informal credentials, and developing an adequate network of contacts among which recruitment could take place.

Perhaps more challenging was parleying initial access into sustained contact. Often simply a degree of amiability ensured that relationships remained functional and constructive. Language, personal appearance and behaviour were valuable tools in gaining access and in amalgamating to improve data quality. This strategy is recognised by many social researchers, who point to benefits of fostering interpersonal parity in relationships, a sense of 'sameness', and avoidance of unintended connotative communication from incongruity of dress, language, or other elements of perceived identity. It can demand a degree of chameleon-like, even polyglot interaction. Walsh (2012, p.253) terms this "impression management":

> What is needed is an impression that facilitates observation and avoids producing obstacles. This, in turn, will require dress that is familiar to the people in the setting and the cultivation of demeanour, speech and habits that fit. The research must be able to create different self-presentations for different settings. Above all, the researcher must establish a large degree of ordinary sociability and normal social intercourse. Without this, pumping people for information can become threatening.

Informed consent was gained from all participants or from suitable gatekeepers (e.g. direct supervisors or organisational directors). All arrangements were entered into voluntarily by gatekeepers; in general participants were made aware of the fact that their participation could be withdrawn at any time. In some instances, where it was deemed that the relationship with a participant might have been adversely affected if undue attention was drawn to the 'observer-observed' aspect of a relationship, explicit agreement was not secured; instead, the gatekeepers were relied on to act as proxies. No use of direct incentives such as financial compensation was made during recruitment or research.

Due to the sensitive nature of the research, all gatekeepers were assured anonymity of their participation and that of all participants, and secure storage of research data.

6.4 Computer-assisted qualitative data analysis software and traditional sorting

Since its origins over three decades ago (Fielding & Lee 1991), 'computer-assisted qualitative data analysis software' (CAQDAS) has become widely used among qualitative researchers to facilitate the 'making sense' of data. Generally, its use includes not just the storage of data but also the organising and structuring, coding and macro-analysis, and presentation of raw data and of analysis.

Many authors point to the advantages of CAQDAS. Sinkovics and Alfoldi (2012, p.109), for instance, argue that while qualitative research is "inherently messy", CAQDAS can help make the process more "manageable and rigorous". Others argue that it presents a risk of fragmenting research, leading to simplistic or incomplete analyses (Bryman & Bell 2011).

The Atlas.ti (version 6.2) CAQDAS package was used during early stages of research. Auto-coding was not employed, although lexical searching was used among other tools of clerical efficiency.

As coding and thematic analysis matured, however, the use of the software began to feel like an impediment to engaging with the data. Although it had offered clear advantages as a labour-saving technology, its utility waned as the project matured. Instead, a traditional approach of 'hands-on' coding and sorting was adopted (see Figure 16 and Figure 17, overleaf).

Figure 16: Photograph showing hands-on process of coding and sorting data

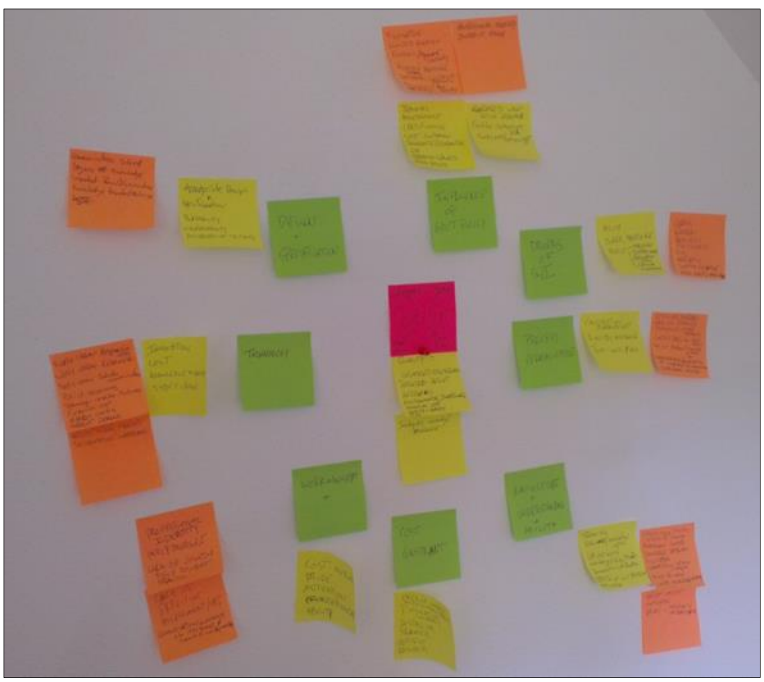

Figure 17: Photograph showing hand-sorting of thematic codes

Woolf (2014, p.5) describes a danger of the ‘direction’ of analysis flowing from software task to analytic task, when instead the opposite should be achieved. Sinkovics and Alfoldi (2012, pp.109–110) describe the potential “dangers in the indiscriminate and overly mechanistic use of CAQDAS”.

Fielding and Lee (1991) described the importance of ensuring the technology did not become a replacement for intellectual engagement by the researcher. In this research, while the technology was advantageous for efficiency at early stages it became an impediment to intellectual engagement.

Once the software was cast-off in favour of a more traditional approach, thematic analysis (i.e. hierarchical or tree coding) became not only more efficient, but a sense of moving closer to the data was experienced. Using scissors, coloured string, field notes, and labels freed the process of coding and sorting considerably and facilitated fresh analysis of the data. This was reflected by considerable shifts in the themes and interpretation of the data.

6.5 Consideration of principles of ethical research practices

This research has recognised the standard ethical concerns in social research.[42] These are understood in several categorisations, as follows.

6.5.1 *Respect of persons*

The welfare of participants must take precedence over all other interests and participants should be treated with courtesy and respect, and only be included in research when fully informed and freely volunteering. Most social researchers accept that when necessary it is acceptable for gatekeepers to offer permission on behalf of others.

6.5.2 Benefice

Researchers have a responsibility to seek maximal benefit for wider society while minimising risks to participants. Researchers should not do any harm to participants or put them at risk.

This research offers direct benefit to its participants in the form of feedback for consideration of their own professional development. The research indirectly benefits the general population as it investigates issues of energy performance of dwellings and may ultimately contribute to reduced energy demand and environmental impact. It contributes to a wider body of research which aims to improve practices.

6.5.3 Justice

Research must be conducted fairly and non-exploitatively. This includes affording the right to opt out of the research, and assuring anonymity and confidentiality

[42] Standards of ethical practice in social research have been outlined in documents such as the Declaration of Helsinki in 1964 by the World Medical Association and the Belmont Report in 1979 by the (USA) National Commission for the Protection of Human Subjects of Behavioral Research.

The Declaration of Helsinki addressed ethical principles for medical research involving human subjects. The Belmont Report established three tenets of ethical conduct for researchers working in behavioural research.

The issue of non-exploitation has been recognised as particularly important given the methods employed in this research. All participants have been recruited as volunteers and have taken part willingly.

6.6 Structure of application of research

Research evolved in three phases which narrowed in focus from discovery to directed investigation of a single organisation. Some research outside of these phases was undertaken (see 'Coincident research').

A list of research participants was provided in Section 6.7.

6.6.1 First phase (background and contextual research)

Discovery research included loosely structured interviews with 18 academic and professional experts working in a wide variety of professional roles. These interviews provided a contextual understanding of prevailing perceptions and concerns about SWI installation practices and performance gaps. Interviews typically lasted one hour. These interviews provided an early introduction to the research field but do not contribute significantly to overall findings. Recruitment of participants in the second phase was essentially independent and not influenced by first-phase participants. As discovery research progressed, it was informed by a parallel review of literature.

Participants were all affiliated with the construction industry or construction research and represented both 'inside' and 'outside' perspectives on the SWI sector. In total, 18 professionals working in England and southern Wales were included in this phase of research; their positions included surveyors, researchers and academics, industry consultants, and staff of insulation manufacturers and supply chain companies. Although their work was predominately conducted in England and Wales, several participants had considerable experience working in Scotland and Northern Ireland. This discovery research, while serving to develop the research questions, does not comprise a significant proportion of the findings that are directly discussed in this document.

From this research, saturation around a limited number of concepts was obtained. These related to persistent performance and quality gaps in contemporary and historical SWI retrofit, the fractured nature of the SWI industry, and its characterisation as being comprised chiefly of micro enterprises which possessed limited levels of technical training.

6.6.2 Second phase

Early contextual work led to a period of short rounds of non-participant observation and unstructured interviewing of actors in a diversity of roles to further explore the themes discovered in the first phase. Professionals and institutions across central and southern England and southern Wales were included (again many had experience in Scotland and Northern Ireland).

In this second phase, roughly 300 hours of non-participant observation and interviewing pursued a more 'granular' understanding of the research landscape and development of the research questions. Interviews and discussion were focused on:

- installation company management working in CESP, CERT, ARBED 2 and ECO projects;
- energy company staff engaged with ECO;
- vocational trainers;
- National Vocational Qualification 2 (NVQ) EWI qualification assessment;
- site management;
- contract management; and
- principal contractor officers in Arbed 2.

Observation sites included:

- installation project site offices;
- installers on site;
- surveyors; and
- a construction training organisation engaged in NVQ 2 training.

Also during this period, a full NVQ Level 2 training course was completed. This served to develop essential proficiency in installation, but also to provide insight into the nature of installer training and a basis for assessing its relationship to scientific understandings of SWI and recognised best practices.

6.6.3 Third phase (primary case study)

The research progressed to more intensive research employing non-participant and participant observation to probe research questions and develop deeper understandings of the research milieu.

Extended study was made of a leading SWI installation company, which works across England and Wales, and routinely has contracts in Scotland as well as non-UK countries. As described in Section 6.3, snowballing and other practical considerations were factors in all recruitment. Foremost of justifications for selecting this company, however was that it: had a long history in the industry (and so would be less likely to be atypical as a new company might be); was a leading company in terms of market share; and indicated numerous times during early stages of recruitment that it was interested in improving practices (hence it would be a good study of drivers of and obstacles to change).

Observation included nearly all professional roles and areas of work in the organisation, while investigation focused on relevance to installation quality and SWI installers. 18 weeks of full-time non-participant and participant observation were undertaken. Observation of contract managers and site managers formed a dominant component of this research; this facilitated regular access to nearly all roles in the organisation. Additionally, observation periods (as participant and non-participant) spanning one to five days were spent with staff in nearly all occupational roles in the organisation, including: surveyors, senior management, business development and sales staff, and a generalist employee best described as a 'technical overseer' or 'quality assurance officer'. Participant observation included assisting in the training of NVQ Level 2 (NVQ2) candidates and four weeks working in the role of SWI installer.

Nearly all observations were made in area-based EWI retrofit projects, with limited observation of IWI; this reflected the balance of SWI work undertaken in the company. A significant proportion of data was collected through shadowing, site inspection and conversing with participants.

6.6.4 Coincident research

Coincident research

Additional work which has supported the three phases of research is described here.

6.6.4.1 COST action

Two weeks were spent at the 'Energy and Sustainable Development' research group in the Faculty of Sciences at the University of Liege to observe building envelope retrofit research and visit several industry sites. The visit took place between 26 May and 07

June, 2013 and was funded through the European Cooperation in Science and Technology (COST) programme, under the 'Smart Energy Regions Action'.[43]

This contributed a contrasting perspective on SWI practices and milieu. Belgium shares many similarities in climate, legislative drivers and building types. In addition to extensive discussion of common knowledge bases, knowledge gaps, and research strategies, observation research provided valuable insights. The research visit contributed to the contextual understanding of retrofitting in the UK by providing international contrasts to norms in industry and industry training. A brief description of site visits and observation activities is provided in Appendix D.

6.6.4.2 Consultation to DECC, DCLG, Ofgem

Two invitations were accepted to share research findings and contribute to discussion with staff of government departments working on SWI-related issues.

The first meeting was hosted by four members of the Department for Communities and Local Government (DCLG) Building Regulations and Standards Team and technical staff working on SWI issues, and was attended by officers working on competent person schemes and building control issues related to SWI. The meeting was also attended by four staff members from the Department of Energy and Climate Change (DECC) in Green Deal and in Science and Innovation roles.

The second meeting was held at DECC offices and at the request of policy officials working on Green Deal, ECO, and in general work in the Science and Innovation team. The meeting was attended by three DECC officers and one official from Ofgem whose remit included energy company responsibilities for carbon reduction projects.

6.6.4.3 Industry feedback

Limited opportunities to assess perceptions of research findings have been presented by discussions with members of industry, as well as presenting findings to various participants. This has provided a degree of theory testing or member checking.

Sessions have included direct feedback to participants in the second and third phases of research, as well as manufacturers and suppliers who have attended workshop presentations of the research, and attendees to a conference held by The Wales

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[43] Project details: 'Thermal insulation retrofitting: theory and practice'; STSM: TU1104-13597

Traditional and Sustainability Building Skills Advisory Group, where this research was presented.

6.7 Roles and pseudonyms

Table 6 contains pseudonyms of those research participants who are directly referred to in this thesis. All participants in this research are presented anonymously by use of the pseudonyms. Where pseudonyms are repeated within text, they may be truncated as acronyms (unless deemed potentially confusing). Similarly, Phases 1, 2 and 3 may be cited as P1, P2 and P3.

Table 6: Roles and pseudonyms of research participants

Phase 1	Phase 2	Phase 3	Coincident research
Building surveyor	Energy Company Officer	Apprentice 1	DCLG Technical Officer
Community Interest Company	Installer John	Apprentice 2	DECC Technical Officer
Community Interest Company Project Officer	Major Company	Business Director	
Construction Waste Expert	New Company	Company Director	
ConstructionSkills Senior Officer	New Company Contract Manager	Contract Manager 1	
Energy and construction details expert	NVQ Assessor	Contract Manager 2	
Expert on UK housing stock condition	System Supply Business Manager	Eastern Europeans' Boss	
Industry Expert 1	Trainer 1	Health and Safety Manager	

Second waste expert	Training School 1	Industry Group Training Representative	
Training School 1 Manager	Training School Owner	Installer Jim	
		Managing Director	
		Phase 3 Company (P3 Company)	
		Quality Manager	
		Quantity Surveyor Head	
		Quantity Surveyor Recent Graduate	
		Quantity Surveyor Senior	
		Sign-up Employee	
		Sign-up Manager	
		Site Manager 1	
		Site Manager 2	
		Site Manager 3	
		Site Manager 4	
		Site Manager 5	
		Tenant Liaison Officer	
		Trainer 2	
		Training School Manager	

6.8 Approach to analysis

Conventions of qualitative data analysis vary widely and adopt stances which range from being closely prescriptive to liberal. This reflects varying aims of research, as well as epistemological positions.

Like ethnography, this research followed an iterative process of asking questions, collecting data, and renewing and readdressing earlier questions. It used coding to facilitate analysis and sought to develop saturation before (or while) developing new questions and carrying out new research.

Ethnographic work produces detailed observation of individuals and their interactions in social-organisational, technical and cultural contexts.

The access gained to the research milieu and the methods employed yielded huge quantities of data. Analysis is based on a substantive approach; there is an interest in the intent and meaning in observed speech and actions, but the researcher's own reaction to non-participant and participant observation is recognised as equally relevant.

Validity has been assessed by the measures of adequate engagement and triangulation discussed in Section 5.3.4.

6.8.1 Iterative analysis

Despite the organisation of this section, inductive research does fit neatly into separate phases of data collection and data analysis.

It begins with data collection; in this research documenting observations and reflections with field notes (i.e. memos) which included photographs. Notes here included summaries, extracts or details from conversations, significant events and everyday observations.

Data were studied iteratively throughout the research and codes were developed and revised. As themes emerged, categories were checked and compared to outline relationships and interconnections between them.

This process is often described as a zig-zagging (Rivas 2012, p.369), or a spiral, helix (O'Reilly 2004, p.177) or succession of loops between data collection and data analysis (and presentation) (Figure 18).

Due to copyright restrictions, content has been removed by the author of this thesis following examination.

Figure 18: An interpretation of iterative data collection and analysis: "The zigzag approach" (Rivas 2012, p.369)

As data collection progressed, and after it ceased, observations were related to contexts from a variety of literature. Positioning the collected data against observations from numerous contexts produced a deeper and richer understanding of observed phenomena. Writing began at early stages of data collection, but did not reach any measure of maturity until collection and analysis had ceased.

6.8.2 Coding and sorting

There is extensive literature debating the virtues and limitations of various approaches to coding. This research has not followed the prescriptive techniques insisted on by many (Ritchie et al. 2003), preferring instead to remain flexible (Mills et al. 2006) and open-minded in the approach to intrepretation of data.

As in GT, this research focused on the construction of codes and themes. A strict hierarchal or tiered approach to sorting was not followed. Instead, 'In vivo', 'descriptive', and 'analytical' codes were developed and sorted and tested in themes and categories as freely. This gradual approach was led by the data and seems far more appropriate to the 'spiralling' ideal of iteration than a progression constrained by hierarchical structure and stages.

Ultimately, codes could be clustered in one – or sometimes more than one – theme (categories). These themes (i.e. 'super' or 'final' codes) were analytical and abstract -- not descriptive -- in nature. This entailed looking at codes across data sets (i.e. multiple observations and sites). This is akin to thematic content analysis and closely aligned to GT.[44]

A process of sorting – to make sense of the data – resulted in the construction of themes (i.e. categories). As described in Section 6.4, after traditional methods of coding and sorting (i.e. not CAQDAS) were employed, development of thematic relationships surged again. Codes were related to one or sometimes multiple themes. Eventually, the production of themes flattened as saturation developed. This is subtly different from analytic induction, in which a hypothesis is tested and repositioned until it 'fits'. In this research, a focus was maintained on the data and the analysis of them.

6.8.3 Analytical frameworks: ways of looking

6.8.3.1 Pragmatism

Mead, Dewey, and other American Pragmatists posited that individual minds must be understood in relation to the minds of others.

They held that human actions reveal relationships between actors and actants (i.e. the entities, agents, collectives or non-human objects or beings which shape or determine interactions or outcomes with humans) and that by studying this, one can come close to understanding perceptions of others.[45]

According to these Pragmatists, we develop knowledge in relation to what is 'useful' to us, and adjust and revise understandings which no longer 'fit'. In this way, 'reality' is

[44] It is distinct from phenomenological or interpretive analyses, which adopt subtle but significant differences of approach and aim. (Rivas 2012, p.367)

[45] A subtle but important difference with the work of George Herbert Mead's thought exists here; Mead was interested in social mediation of human perception and action. He argued that behaviour toward 'objects' tells us something of the individual's perception, but equally, that we must understand this as a reflection of a collective definition or social landscape in which the action is placed.

actively created; it does not exist statically. To understand the reality of those we observe, we must access their perception and -- in so doing – understand that this perception is rooted in shared meaning and manipulated experience.

This point of view is a predicate for many contemporary epistemological debates. It underpinned the approach to studying actors in SWI in this research. Accessing the perceptions of others was recognised as fundamentally difficult, impossible to achieve fully, but not altogether impossible in partial realisation. This research has accepted that by observing actions and interactions, some understanding of motivation and perception may (with possible fallibility) be developed. This understanding is assumed to be imperfect, but nevertheless -- in the context of repeated observation – offers a degree of useful insight.

6.8.3.2 Symbolic interactionism

Like Pragmatism, Symbolic Interactionism recognises that meanings are co-produced, but it asserts interactions between people and their environments are essentially unknowable. It argues that definite and objective knowledge of 'a reality' is impossible.

One way to consider patterns of work on a retrofit site is to explore what they might signify about relationships between actors and actants. From observation and interacting with workers on site (or others), one might presume to understand collective attitudes and the viewpoint or experience of workers. Symbolic Interactionism tells us that the 'reality' of others is far too complex.

Reality in Symbolic Interactionism is constantly negotiated and deeply embedded in social and technical contexts. This context is essentially indecipherable to an outsider. As observers, we may be able to develop some understanding of this reality, but it will always be incomplete.

The use of participant observation in this research is a strategy to access a reality which may be shared by SWI professionals. In analysis, personal experience is joined with observation. This goes some way toward resolving the uncertainty about 'what is knowable' about interactions between actors and actants, and contributing an 'inside perspective' to the realities in SWI milieux. Of course, this can only tell the reader something about the researcher's reality. Nevertheless, by gaining some experience outside of simple observation, it is hoped that understanding is made richer and more nuanced.

Behaviour is based largely on social interaction (historical and immediate), but not as a result *of* it. Individuals are recognised as having a capacity for reflection and change. Actions are rooted in our definition of events and environments. To the extent that past experiences form our present actions, this is primarily the result of active thinking. This contrasts more structuralist analyses that see thought and behaviour as simply conditioned (i.e. determinism). (Charon 2007)

The delineation of potential improvements that is made by this research is drawn from an understanding that interventions and changes to organisational structure, technology, communication and knowledge exchange mechanisms (among other aspects of context) can have a real impact on behaviours and actions.

6.8.3.3 Conceptions of self and society

'Me' and 'I'

Sigmund Freud's[46] American contemporary George Herbert Mead differentiated between components of the self by using 'me' and 'I'.[47] Mead used 'I' to refer to the active and individual response of the individual to outside stimulus. He used 'me' to reflect learning about the outside environment and developing a 'sense of self' within that environment. For Mead, 'me' is shaped by society and environment and reflects accountability to norms, expectations, and the collective force of what is outside the self (2009, p.277)[48]. In contrast to Freud, Mead held that the individual had a capacity for reconstruction, and that humans must be understood within their social contexts.[49]

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[46] Freud distinguished between the self's 'id' (unconscious urges ruled by the 'pleasure principle'), 'superego' (partial conscious 'censor' derived from societal and family values) and 'ego' (the response of an individual to its community)

[47] Mead adapted 'me' and 'I' from the work of William James.

[48] There is a parallel here to Freud's assessment that the ego acts as a 'censor'.

[49] This is an element of Mead's thought for which he is recognised as providing the foundations of Symbolic Interactionism and Interpretivism.

In response to ‘me’, the ‘I’ makes decisions, evaluates actions, and actively exists. He writes, “The “me”…presents the situation within which conduct takes place, and the “I” is the actual response to that situation“.

There is also a tendency to possess multiple ‘mes’ (Mead 2009, p.142): “We carry on a whole series of different relationships to different people. We are one thing to one man and another thing to another…”.

These arguments inform analysis of SWI professionals in this research. Professionals are understood to actively engage and respond to the environs and norms they work in.

Meads arguments also provide an important way of understanding the crew setting in which installers work and organisational structure in which second tier actors work. Mead identifies that in working collectively, a “fusion” of ‘I’ and ‘me’ occurs (2009, p.273):

> In a situation where persons are all trying to save someone from drowning, there is a sense of common effort in which one is stimulated by the others to do the same thing they are doing. In those situations one has a sense of being identified with all because the reaction is essentially an identical reaction. In the case of team work, there is an identification of the individual with the group; but in that case one is doing something different from the others, even though what the others do determines what he is to do.

In teamwork, Mead recognises that a degree of trans-identification occurs. He argues that as the collective goal supplants the individual experience, we are innately contented -- though we retain self-awareness. He explains (2009, p.276) that one is instinctively:

> awake to the way in which other people are responding in order to do his part in the team work”. One maintains “…a sense of the common end interpenetrating the particular function which he is carrying on. Mead’s elucidation of teamwork has great relevance to this research given that installers – and an array of actors around them – work communally in retrofits.

These ideas form part of the tradition of understanding identities as both individual and collective. This research (particularly in its discussion of results) recognises that actions cannot be understood as rooted solely in individuals. It studies individuals in the context of their socio-cultural constructs – as possessing both ‘me’ and ‘I’.

STS and Actor Network Theory

'Installation quality' contains a complexity of factors and is the outcome of innumerable interactions and decisions. These are shaped by a diversity of influences rooted in the SWI 'landscape'. In turn, influences are mediated by individuals, actants and the structures within the landscape itself. Quality is plainly a 'human product', yet humans are situated in – and respond to – a diversity of influences.

It would be an incomplete analysis to understand quality only through a social-cultural-organisational analysis. Individuals do not produce 'products' in isolation, nor simply within social constructs. Since the work of Latour, Callon, Law (Latour 1987; Callon & Latour 1981; Law 1993; Law & Hassard 1999) and other authors in the 1980s and early 1990s, constructivist analysis has highlighted the importance of relationships between actors, materials, and concepts in the production of work. Actor Network Theory (ANT), which emerged from their discourse, holds that the agency and constraints of technology exert normative and determinative forces on the processes of doing and producing.[50]

ANT suggests that production (which can be understood as any outcome of interaction) occurs within socio-technical assemblies (e.g. Latour 2007). This presents an overwhelming 'messiness' of interaction. We come to understand that SWI work is shaped by interconnected and inter-negotiating forces between actors (e.g. objects, humans, machines, ideas, organisations, geographical arrangements) (Law 2007; Hitchings 2003, p.100). Described differently, interactions between actors and actants show producers' behaviours in the context of technical and environmental milieux (Suchman 1987). Where the processes and forces by which actors and actants exert influence toward each other or are shaped by other forces within a system cannot be understood by the observer, ANT describes this as a 'black box'.

[50] ANT holds that 'system builders' enlist other actors as they work toward a given goal. As they do this, all actors become entrenched into roles and become in part defined by their relationship to other material and non-material entities. The division between one actor and another becomes less and less significant. ANT argues that semiotics are just as meaningful as other structures. Actors, materials, and concepts are constantly defined and redefined in relation to each other. Technologies are defined as relationships between actors and material objects. Hence the role and function of any one actor or material item is intrinsically related to that of another. In this relationship, there is continual scope for transformation and reconfiguration. There is also a determination of power. ANT describes entities in relation to each other and disbands earlier conceptualisations of socio-technological structures. (Latour 1987; Latour 1996; Law & Hassard 1999; Latour 2007).

ANT is notoriously difficult to describe. It can be seen as a 'non-theory' and it rejects reductionist models of analysis. It is located within wider debate in Science and Technology Studies (STS). Similar postmodernist and symbolic interactionist approaches have become central modes in contemporary 'ways of looking'.

In analysis of data, this research has drawn on some poststructuralist tenets of ANT. For instance, it recognises that meaning and definition are negotiated between actors, material and non-material entities -- and are interpreted afresh in each moment and in each setting. It examines product choice, installation technique, and knowledge transfer as intrinsically related to these negotiations. In particular, by viewing nonhuman actors as members of the 'SWI milieu', it has been possible to explore more deeply the influences of technologies, organisations, concepts and understandings, norms, and particulars of retrofit programmes (e.g. CESP and ECO). This probes more deeply the understanding of observed decisions, actions and interactions.

This work does not attempt to develop a complete analysis or outline its observations solely through ANT; like many other authors it merely draws on some concepts and lenses which are particularly useful. Symbolic interactionist thought, and ANT in particular, has become an almost commonplace approach to interpreting workplaces and the 'doing' of work. For instance, Gray and Gibson (2013) explore threats to the sustainability of agriculture in Kansas posed by climate change and industrial agricultural systems, by employing ANT to understand farmers within the complexities of industrial agricultural networks. Gherardi and Nicolini (2000) used ANT in their workplace safety practices and norms in the construction industry in Northern Italy and showed that safety-related knowledge is situated, negotiated, and relational between actors and artefacts. Kettley (2005) explored craft as a cultural construction through an analysis rooted in ANT. She explored themes of authenticity, exclusivity and authorship between traditional craftwork and contemporary craft practices (jewellery-making) and design. She explores both the collisions and scope for transference between these realms.

Harty (2005, p.517) discusses aligning "multiple actors and artefacts towards a specific goal or vision" and urges innovative growth in construction work. He bases his paper on the Heathrow Terminal 5 project and distinguishes between 'bounded' and 'unbounded' innovations in construction work. He draws on symbolic interactionist analysis and argues that by understanding projects in this way, a process of 'engineering' of “orderings and configurations of different actors and objects” can lead to “not only just new or transformed practices, processes or systems, but also, potentially, a transformation of technologies” (2005, p.517). In a similar vein, this thesis engages with the ANT ‘lens’ as it evaluates SWI quality.

6.9 Summary

This chapter and the chapter that preceded it have described the approach to research and analysis and the development of research methods in this project. These chapters have presented a wide range of theory and research traditions and conventions which have informed the approach and method design.

The following two chapters present the main findings of research and report a broad selection of observations.

7 Results: practices of installation and specification

7.1 Overview

This chapter is the first of two chapters reporting the findings of the field research. It begins by explaining the approach to reporting results. A brief description of the 'SWI landscape' as observed in research is then provided. This is followed by presentation of an assortment of data related to poor installation and specification practices, which were gathered during research. Finally, it characterises the processes and norms of SWI design and specification as observed in the field.

Chapter 8 presents data related to factors understood to influence practices and the realisation of 'quality' in retrofits.

7.2 Presentation of data

This study produced a high volume of data, as is typical of research using similar methods. This poses a challenge to succinct and useful presentation of the data.

Ethnographers generally present data using thick description or narratives. In this way, large quantities of diverse data can be managed without the need to extract significant themes overtly in text. These accounts often follow the chronology of research, or outline themes along chronological structure, and so to an extent are 'self-structuring'. This approach to presentation has been rejected to enable a clearer discussion of the implications of data and of its context. The focus in this research has not been on the experience of collection or on anthropological description. Although the employed methods have much in common with ethnographic work, this research has important differences with this tradition (Section 5.3).

Another way to present results might be organisation by research method. Because methods have been employed in parallel, presenting collected data separately would be confusing and unhelpful.

Chronological reporting has also been rejected. Many data appeared repeatedly at disparate points in the linear progression of research, but there was little significance to this distribution. Examples have been selected for presentation where they are typical of issues or are otherwise noteworthy. Because data relate to a very wide array of topics, to present examples chronologically would result in a chaotic text.

Presenting a hierarchy based on density of codes would entail a false analysis. Frequency of occurrence does not correlate to significance. Similarly, to create a hierarchy based on ascribed significance or importance to the research would be misleading. Even if the entailed evaluation could be justified, it would not be helpful; what is important to one aspect of quality or research questions would be less so to another. Any such hierarchy would be simplistic.

Since a traditional ethnographic approach to reporting has been rejected, it has been necessary to arrive at a meaningful alternative. The high volume and diverse nature of data has called for an ordered structure.

A relatively conventional approach to presenting research is adopted, in which raw data is shown, analysis is presented and then discussion is provided.

Questions, theory, conclusions and new questions were developed iteratively in this research. The 'answers' to questions have not been arrived at subsequent to data collection and interpretation has occurred throughout the research. The data are reported in this chapter and in Chapter 8 in a structure conducive to showing the reader the themes of analysis which emerged from the iterative process of research. Aligned with the argument by Spencer et al. (2013), it is accepted that a different researcher interpreting these data might have arrived at somewhat different conclusions. As Spencer et al. argue, it is held that research should produce a meaningful, but not necessarily repeatable, interpretation of data.

Photographs and short narratives in this chapter and in Chapter 8 provide the reader with the range of evidence which contributed to the iterative development of theory.

The final analysis of data – the point at which saturation matured and codes, categories and themes became stable – is shown in Figure 19 (overleaf). The themes shown in this analysis have provided a useful starting point for presentation of results. The themes are:

- Workmanship;
- Design and specification practice;
- Technology, constraints and conservatism in practices;
- Process management;
- Knowledge, understanding and ability
- Drivers of insulation work;
- Influence of UK Government and public policy; and
- Financial cost and expenditure.

Some data have close relationships to more than one category or theme and so might have been presented under more than one theme. This has been avoided in order to simplify presentation; however, where this occurs the wider relevance is discussed.

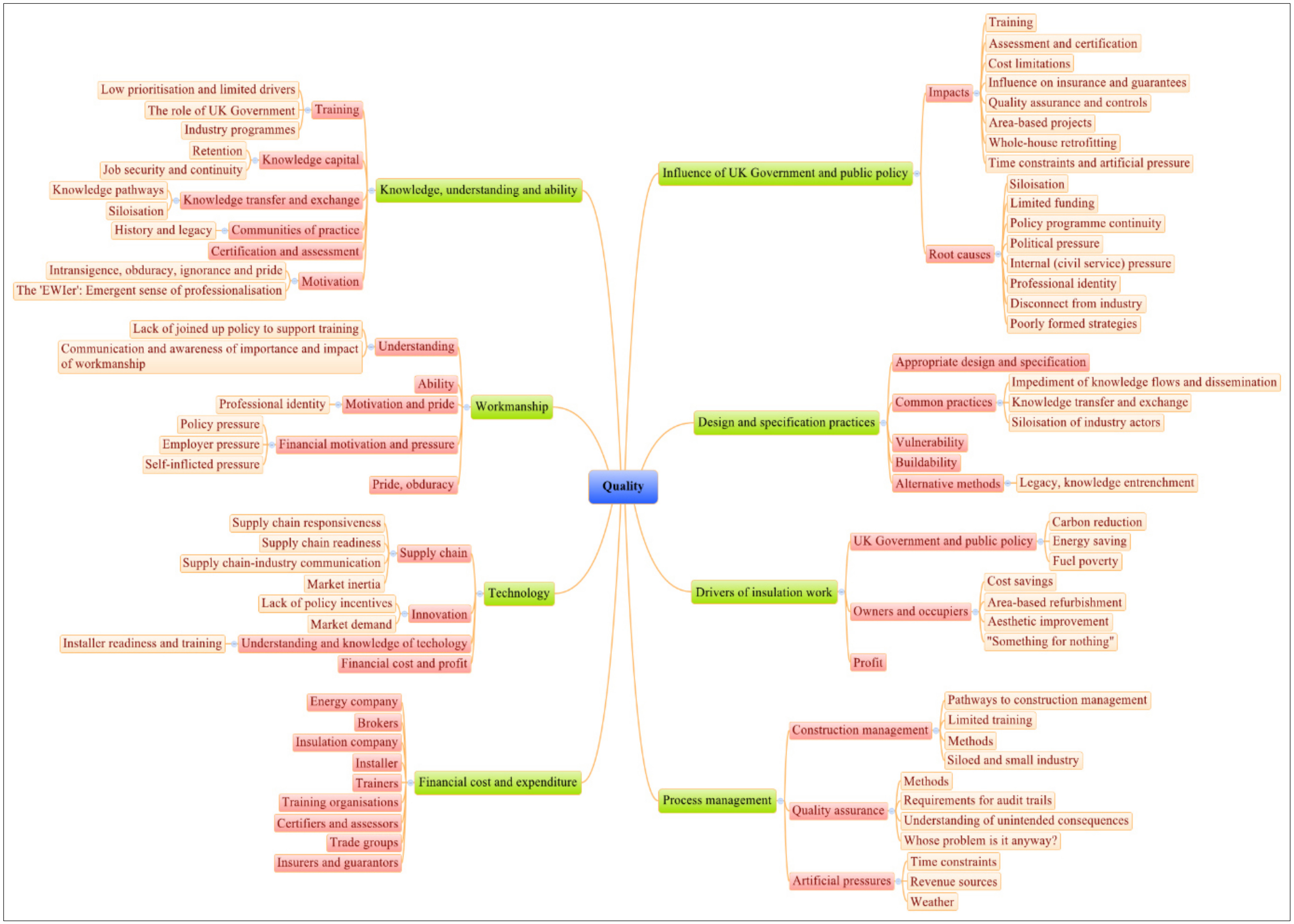

Figure 19: Diagram of codes, categories and themes derived from analysis of research observations

In this chapter (the first of two results chapters), the first two themes – 'Workmanship' and 'Design and specification practice' are presented. The order in which these are presented does not convey ascribed significance; to ascribe a hierarchy would be simplistic, in much the same way as ranking significance of data would be. Categories of data in Section 7.4 are presented alphabetically to minimise implied significance.

Discussion presented in Chapter 9 relates the data to literature, evaluates theoretical triangulation, and addresses the significance of the findings.

7.2.1 Selection of data for presentation

Because of the very high volumes of data, naturally, some selection of data for presentation has been necessary. During field research, there was a natural inclination to focus on examples of problems – not least because evolving questions were focused on explanations for poor practice. By any measure, poor practice was commonplace. As such, much more of the recorded data focuses on problems than it does on examples of 'good' practice.

Although this research did not attempt to quantify or catalogue practices of installation or specification, characterisation is founded on prolonged observation.

Despite the fact that the evidence shown here displays examples which could be found on a significant proportion of retrofits, this thesis is careful to avoid drawing its arguments solely on the pervasiveness of poor practice. Instead, this evidence is provided to give the reader a sense of the types of identified problems, in order to form a basis for discussion about factors related to practices. The data reported in this chapter are selected because they are representative of the wider set of data. Although poor practice was remarkably pervasive, the proportion of poor practices pointed to in this reporting should not be taken as representative of proportions found in the field.

7.3 Changing landscape

A dramatic and indisputable growth in the installation industry was palpable from the earliest stages of research. Such was the increase in EWI retrofitting that several participants[51] reported that regional shortages in scaffolding had become common.

P3 Company's business turnover had doubled in the latter half of 2012 alone. Historically, 40 per cent of the company's turnover had been in new construction. Contract Manager 1 reported "things are changing completely… ECO is slowing refurb this year, but [for the most part] these programmes have been pushing the business toward refurb completely in the past couple years." A surge in retrofit work almost exclusively underpinned a growth in turnover over the preceding three years from £7 million to £15 million to £25 million (of which over 90 per cent was EWI; IWI made up roughly 5 per cent and had only "really started" recently under CESP. The vast majority of this growth in retrofitting took place in social housing – accounting for roughly 80 per cent of turnover.

Similarly, this transformative growth was apparent in Phase 2. 'New Company' had transitioned to EWI work having previously been focused on photovoltaic installation, and 'Major Company' was investing significantly in development of its EWI business, having previously been reliant on a range or refurbishment and retrofit projects.

Aside from the evidence of significant growth across the installation industry, reporting of a legacy of poor practices was consistent throughout all three phases. Many participants working within or outside of the industry expressed concern about the inconsistency of workmanship, and – particularly among those with advanced technical expertise – concern was voiced that inappropriate specification might be presenting unacceptable moisture-related risks.

Despite this, other actors appeared unaware of this legacy or dismissive of its legitimacy or significance. Several actors in each phase reported that workmanship was generally improving. Most explained this with reference to

[51] NVQ Assessor (P2), Contract Manager 1 (P3) and Energy Company Officer (P2)

the impact of CESP and ECO; some pointed to it being the result of a more general evolution in the industry.

An illustrative example of perceived problems in workmanship can be found in an interaction between Sign-up Employee and a prospective household enlistee under an ECO scheme (P3). During a ‘door knock’ interaction, the owners stated that they had not yet enrolled because of misgivings about workmanship. They asserted that P3 company and a competitor had “been racing” to complete jobs, and they felt that damage to property was rife (e.g. scraped window cills, “water running down behind” EWI systems). They stated, “it’s been quantity over quality, they just been racing through here”. Privately, SE expressed what appeared to be genuine disagreement that workmanship was typically problematic and criticised the homeowners for being “awkward”.

7.4 Examples of poor installation and specification practice

7.4.1 Aesthetics

Significant defects of both aesthetic and functional character were very common (perhaps appearing in one of two retrofits observed), with more serious defects observed in roughly 5-10 per cent of retrofits and minor defects nearly ubiquitously. Examples of observed defects are provided in the following subsections.

7.4.1.1 Render

Poor rendering practices were extremely common across Phases 2 and 3. Most commonly, these related to pillowed or uneven surfaces (Figure 20), soiling of adjacent surfaces (Figure 21, overleaf) or of garden spaces or pavements.

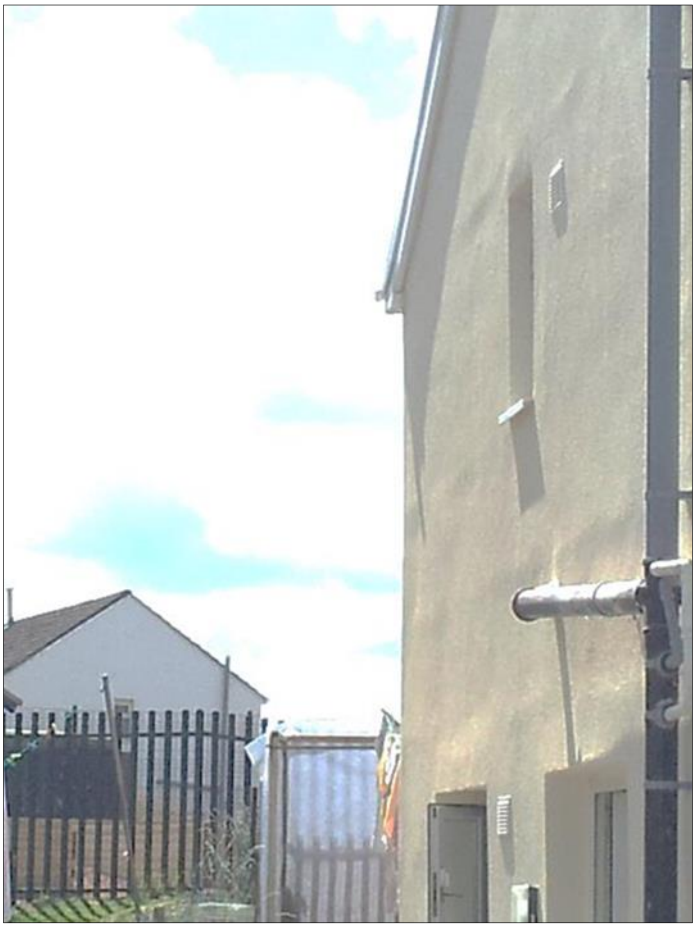

Figure 20: Photograph showing uneven surface of render

Figure 21: Photograph showing render on window, cill and cornerbead

These practices might be surprising given that the most common route to employment as an SWI installer was via a background in the plastering trades or via plastering vocational training courses. Ascribing poor practices to incompetence or lack of motivation is difficult. Although competency was at times questionable, in general, practices appeared rooted in installers' indifference or prioritisation of speed above workmanship.

Further evidence of the pervasiveness of poor practices came from Training School 1 (P2), in which experienced worker candidates laughed when speaking of poor adherence to rendering guidelines, saying of acrylic primer "we never let it go off [before proceeding with installation]". Similarly, in New Company (P2), installers reported that they "never" washed, sealed or otherwise treated dusty rough-cast concrete walls before installing mineral wool EWI systems. These systems were installed with adhesive only, which by supplier specification must be installed on clean and sound substrate.

Figure 20 and Figure 21 show quality which is poor and would likely affect potential resale value of the houses. Site and contract managers would often knowingly overlook such practices, although at times rework would be ordered. Generally, unless complaints were made by owners or occupiers, poor workmanship went uncorrected.

As a way of reducing the difficulty of achieving surface uniformity, P3 Company avoided expanses of render more than one story high (by use of banding or trim). This was the only mitigating action recorded. In all other cases, poor workmanship was addressed retroactively.

7.4.1.2 Gas services -- aesthetics

Gas pipes and meter boxes were – with one exception -- left in-situ and insulation was placed around, rather than behind, services. This was a common area to see poor attention to detail. Figure 22 and Figure 23 (overleaf) show examples, in which the edges are not straight, plumb, or unaligned at either side of the cutaway.

Figure 22: Photograph showing uneven edges around gas meter box

Figure 23: Photograph showing uneven spacing around gas supply pipe

Gas Safe regulations require horizontal access to either side of shut-off valves. Rather than allowing a space the width of a spanner, by far the most common solution observed on sites was to leave a large uninsulated area. Poor detailing as shown here was remarkably common.

The practice of leaving services in-situ was driven by cost. Many participants from outside the industry, and industry management officials saw the practice as regrettable. Management officials argued that relocation of services was unaffordable given compensation levels from energy companies (through CESP, ECO and similar programmes).

Further issues related to gas services are presented in Sections 7.4.1.2 and 7.4.5.3.

7.4.2 Environmental impact on site

Several instances were recorded of poor environmental impact from site work and there was generally little indication that installers or managers understood – or had been trained in – responsible practices.

Plaster and PVA waste and cleaning water were frequently poured into street drains in observations in both Phases 2 and 3. One anecdote was related that in P3 Company, installers had "killed a £20,000 carp… [in a resident's garden] from chemicals in the waste water [from rendering which was dumped on site].

Several occasions of electrical generators being operated without drip trays were recorded in Phases 2 and 3.

Cutting and handling EPS led to considerable quantities of polystyrene scrap polluting local areas; installers rarely controlled this waste adequately although in some cases a reasonable proportion was captured by sweeping (Figure 24). Although one installer used a toothless saw (Phase 3) and one crew used a hot wire (Phase 2), all other observed installers used carpentry saws which created significant scrap waste.

Figure 24: Photograph showing polystyrene waste from cutting of EPS

Limited understandings of site environmental impacts were reflected in both Training School 1 and 2. In TS 1, model answers were provided to the NVQ 2 test question, 'How do you protect the environment while working?'; these were limited to "use polythene and trays under your generator and window protection while dashing" (an almost identical answer was provided in Training School 2). In response to the question 'How can you reduce carbon emissions on site', the model answers were limited to 'use 110 volt tools, mix render by hand, and car-share'. More significant emissions would include limiting the use of heavy equipment, transport distances for material and labour, sources of electrical power, and continuous use of electrical generators for site offices.

7.4.3 Moisture

7.4.3.1 Bulk moisture ingress risk (EWI)

Exclusion of moisture ingress in EWI relies on the integrity of outer layers (e.g. render or brick slip) and seals at system boundaries. Compromised integrity presents high likelihood of wetting of EWI systems or building fabric from ingress of precipitation, condensed moisture (e.g. dew). Instances of poor practice and apparently limited understanding of the risk they posed was widespread throughout Phases 2 and 3.

Verge caps

Typically, existing eaves give adequate coverage of EWI retrofits. The overhang of roofs at gable ends (i.e. the rake), however, is often inadequate. The extension of a roof ('laddering') over EWI at gable ends was rare in observations. Verge caps, which are the alternative method, are a somewhat controversial approach; many experts believe they are particularly prone to moisture ingress. Nevertheless, most manufacturers and system suppliers allow for this approach.

Several instances of very poor workmanship on verge caps were recorded. The following were recorded in Phase 3. Figure 25 (overleaf) shows a verge cap which is angled in toward the gable wall instead of away from it. This installation also did not include the required bead of silicone sealant at the junction between trim and roof. Reports from management officers as well as installers on this site indicated that omission of sealant had occurred several times in previous weeks. Figure 26 (overleaf) shows a fairly common occurrence: the gap between verge cap and roof here is far too large to be sealed with conventional silicone sealant as is being applied here. Figure 27 (overleaf) shows a significant gap between segments of verge trim, which presents a direct pathway for moisture ingress.

Training Instructor 1 spoke of the pervasiveness of this problem in industry citing a hypothetical example: "If you notice on the ends [between verge trim and roof], there's a fucking inch and a half gap. The silicone's gonna fail or it's not even there".

Figure 25: Photograph showing improperly installed verge cap

Figure 26: Photograph showing a large gap between verge trim and roof sealed with silicone caulking

Figure 27: Photograph showing gap between verge trim segments

Window and door openings

Figure 28 (overleaf) shows adequate clearance from doorstep in order to protect EWI system from coming into prolonged contact with typical snow fall and rain. Figure 29 (overleaf) shows similar practice; however, in order to accomplish this, the insulation has not been extended to the DPC of the wall behind it.

Figure 28: Photograph showing appropriate practice offsetting EWI over doorstep to protect from moisture

Figure 29: Photograph showing additional example of appropriate practice offsetting EWI over doorstep to protect from moisture

Figure 30 (overleaf) shows a remarkably common failure to provide space above the doorstep to protect the EWI from moisture. Here, the system employs mineral wool which is likely to absorb significant quantities of moisture by capillary action. This figure also shows a gas shut-off valve to the left of the door which has been boxed in. Boxing-in the gas shut-off valve will make emergency or maintenance access difficult; this issue is discussed in Section 7.4.5.3.

Figure 30: Photograph showing vulnerability of EWI to moisture cause by lack of offset over doorstop

Five instances of insulation left exposed beneath window cills adjacent to door openings were observed across Phases 2 and 3. In three of these, the fault was not recorded by contract management. Figure 31 (overleaf) shows an example of insulation extended beyond a window cill and undercill (which also has not been placed in line with the original cill as it should have been). This poor workmanship poses a near certainty of moisture ingress.

Figure 31: Photograph showing insulation board extended beyond cill and undercill

Plumbing

BBA requirements and good practice conventions and guidance dictate that where connections in plumbing are made within a wall or SWI system, these connections must be compression-fit or welded. Contract Manager 1 and Site Manager 3 complained of past instances of push-fit connections being used by subcontracted plumbers (P3). A failure in connections would cause saturation of the insulation and wall. If minor, this leak might go unnoticed but would cause loss of thermal performance and present moisture-related risks. A more severe leak, once recognised, would necessitate substantial repair.

In Phases 2 and 3, overflow pipes draining to the outside were seen not extended. This would likely lead to significant wetting of the wall and potential moisture ingress.

Failure in exclusion layer

Poor rendering practice and storage of render materials -- as described in Sections 7.4.1 and -- might lead to failure (e.g. shrinkage or movement) which would cause cracks and allow ingress of moisture. Poor practices were observed, but no post-completion site inspection captured evidence of render failure.

7.4.3.2 Vapour ingress risk

Vapour ingress must be controlled to avoid condensation below dew point in interstitial spaces. The risk of this occurring in EWI would most likely be present only in unusual summertime conditions (e.g. with warm humid external conditions and internal air conditioning). No recognition of the significance of this risk (nor its potential exacerbation in future due to climate change) from any specifier or member of industry was recorded in any phase.

The risks of interstitial condensation are of course far more significant and widely recognised in IWI.

Despite this, the limited IWI installations recorded all displayed a dearth of control strategies for internal vapour. In these installations, PUR and PIR were fixed directly to internal surfaces and plasterboard and skim finishes were installed in direct contact to the insulation. Substantial gaps between insulation boards were commonly left by installers; these gaps would allow significant pathways for warm moist air to be driven outward through the IWI system (see Figure 32, overleaf, which also shows incorrect placement of pins).

Figure 32: Photograph showing large gap between IWI boards and incorrect locations of pins

In the same installation, Figure 33 (overleaf) shows common practice for relocating electrical fittings. The entire system was installed here without a VCL, and significant moisture pathways can be seen here around the fitting as well as in the slit cut out to accommodate the electrical wiring.

Figure 33: Photograph showing electrical fitting relocated in IWI installation

Figure 34 (overleaf) shows a similar approach to accommodating existing electrical fittings (as in the previous examples, no spray foam filler was applied). In addition, poor butting between boards and at the inside corner leaves uninsulated areas and vapour ingress routes. Similarly, a large gap above the floor exists at left. Finally, the horn of the original window board has not been cut flush with wall to allow installation of contiguous insulation board; instead, a section of insulation has been removed and a large gap created (the wooden board will likely be below dew point in winter).

Figure 34: Photograph showing IWI installation with multiple gaps

Figure 35 shows an IWI installation in which the original coving has been left in-situ and the first floor joists in the ceiling void have been left as built (bricked-in) and the surrounding wall left untreated. Access for plumbing (to be surface-mounted) has been provided via a rough opening, without sealing or provision of vapour control.

Figure 35: Photograph showing practice typical of observed IWI installations. Note large uninsulated area at ceiling-floor void and open pathway for vapour movement around pipes

Figure 36 (overleaf) shows significant gaps between boards and several unnecessary holes created by drilling due to hastiness in finding pin location. It also shows pieces of insulation measuring less than the minimum allowable dimensions and left unfixed. Pinning on all boards is inadequate and does not meet minimum specification. Finally, the existing coving has been left in place and this area (and ceiling void above) have been left untreated.

Figure 36: Photograph showing numerous faults in IWI installation

Other potential routes for vapour ingress were not directly observable; for instance, routes behind switch plates or outlet covers (observation did not capture second fixing of electrics) or failure in the plasterboard or plaster might be caused by poor practice. In Figure 37 (overleaf), the existing window board protrudes into the IWI and a joint between insulation boards has fallen at the window edge. Both of these present a risk of cracking in the plaster (thus allowing substantial vapour ingress), but no post-installation surveys which might catch such occurrences were conducted.

Figure 37: Photograph showing gap and unevenness between two IWI boards, joint between boards at window edge and moisture resulting from poor handling on site

7.4.3.3 Vapour risk - exterior

Observed SWI systems employed either 'vapour open' or 'vapour closed' insulants (see Section 2.5.2.3). EWI was covered with acrylic or silicone render or brick slip systems. EWI and IWI systems were applied directly onto original walls, which were generally constructed using cement render or unrendered masonry with cement mortar.

Regardless of the permeability of the applied SWI, the permeability of the original constructions varied considerably. Significant potential for diffusion of exterior vapour into building fabric might be driven by pressure differentials caused by differences between inside and outside temperature or humidity. Routes for vapour diffusion would be presented by cracks in existing render, between masonry and mortar, between walls and windows, doors, or service penetrations, or across porous monolithic concrete walls (e.g. in Wimpey or BISF housing). Even if low permeability SWI and render is employed, significant routes are present behind EWI (particularly, for instance where installed onto pebbledash without parge coating).

Under future climate conditions it is likely that to address overheating, interior air conditioning be employed much more commonly than it has been to date. This presents the potential for exterior vapour to be driven across EWI toward colder interstitial spaces within walls, or across walls onto the colder back side of IWI. This may lead to unmanaged interstitial condensation.

A similar situation was observed in installation of a VIP system against a hard-to-treat cavity wall and timber frame infill by Major Company (P2) (Figure 38). Joining the visible VCL to the underside of the existing window cill and to the brick on either side of the VIPs was not attempted by the installers. Abandoning a more robust approach, even a silicone sealant installed here would be difficult to apply with complete vapour occlusion. This installation is highly likely to allow outside air to condense during summer on surfaces inside the insulation (this installation was in southeast England; climate change is predicted to increase incidences of summertime overheating and air-conditioning – already employed in many homes == may become more common). Conversely, in winter, the timber battens which are visible are likely to be a site for condensation of escaping internal moisture.

Figure 38: Photograph showing vacuum insulation panel installation, showing difficulty of vapour occlusion

Figure 39 (overleaf) shows a similar VIP installation, on the same project. In this photograph, the failure of the foil tape (which is intended to serve as a VCL) to maintain complete adhesion can be seen. This has occurred between VIPs (top-centre) where the VIP wrapper has caused an obstruction, and between VIPs and the phenolic foam infills where a difference in thickness has caused too much tension on the tape.

Figure 39: Photograph showing vacuum insulation panel installation, showing failure of foil tape vapour occlusion

VIPs on the UK market are available in a limited number of dimensions and at present are only available in rectilinear shapes. This presents an obstacle in areas such as gable ends and small runs of open wall area (Figure 40, overleaf). The only solution at present is to patch around VIPs with low lambda-value insulation (e.g. phenolic foam board) to attempt to maintain similar insulation thickness while achieving relatively homogenous u-value.

Figure 40: Photograph showing limitations of standardised dimensions of vacuum insulation panels

7.4.4 Potential for mechanical failure

Mechanical failure could occur due to product failure (e.g. delamination of insulation boards) or faults with workmanship. No instances of mechanical failure due to product faults were recorded.

Several instances related to risks of failure due to workmanship were recorded, however no failures were observed.

The propensity for failure of adhesive due to improper surface preparation or storage and application conditions was recorded; these workmanship issues have been described in Sections 7.4.1 and 8.5.8.2.

Much more common was improper pinning procedure. In most cases, this could reasonably be predicted to endanger a minor failure such as cracking due to slight movement.

Pinning specifications dictate regular spacing, minimum board size (typically 200mm), and flush installation, perpendicular to the board surface. Very often, this specification was not followed neatly. Site and contract managers would critique work based on pinning patterns and in some instances demand rework of poor pinning. It was relatively common, however, to see poor practice allowed, or occurring unnoticed. Figure 41 shows the following breaches of the system supplier's specification:

- uneven spacing;
- pin at upper left too far from insulation boundary;
- pins sunk below insulation surface;
- broken pin head;
- pins not perpendicular to insulation board;
- patched in board at upper right less than minimum allowed board dimensions;
- pin missing at corner of window at upper left of photograph;
- board at bottom right not adequately pinned; and
- boards at top centre are uneven, indicating incomplete contact of upper board to wall.

Figure 41: Photograph showing multiple instances of improper pinning

7.4.5 Safety

7.4.5.1 Blocking of flues and vents

Four reports were heard of gas flues or back boiler passive vents being inadvertently blocked during installation. One report in P3 Company related to a projecting gas flue (as shown in Figure 42, overleaf) which was taped over with masking on a Friday afternoon, in order to protect it from render which was due to be applied on a Monday morning. As was normal in EWI installations, the house was occupied. On the Saturday, the occupants reported that their boiler was not working. Fortunately, the boiler had cut out automatically and the residents were not injured by unvented combustion gases.

Figure 42: Photograph showing boiler flue projecting through EWI system

In other instances, passive vents were simply 'boarded over' during the course of installation. This was reported by a site manager in P2 as a particularly significant risk when vents or air bricks were not recorded on the 'spec sheet' provided to installers before a project commenced.

Additionally, in Phases 2 and 3, several passive vents were observed to be partially blocked by scrim, basecoat, or render (not boarded over), due to poor detailing around openings.

7.4.5.2 Soil and vent pipe

Soil and vent pipes (SVPs) were often replaced during works and it was not uncommon to observe a lack of compliance with building regulations which stipulate that SVPs must extend above the roof line. Figure 43 (overleaf) shows an example of improper installation; here the SVP is situated directly beneath the soffit, which poses a risk of sewage gases flowing into the loft space.

Figure 43: Photograph showing improper installation of soil and vent pipe

7.4.5.3 Gas services -- safety

As described in 7.4.1.2, gas supply lines and gas meters were only once seen to be relocated outside of an EWI system. If leaving meter boxes and supply lines in place, good practice would be to allow sufficient space to remove the meter if necessary. Compliance with supplier rules and fire safety guidance requires leaving access and horizontal clearance around the shut-off valve (typically cited as 250mm to either side). Figure 44 (overleaf) shows an example of a relatively common workmanship fault in which the valve has been fully blocked by the EWI system. Note also the uneven height of the insulation to either side of supply line – a not atypical aesthetic blunder.

Figure 44: Photograph showing gas supply line and shut-off valve blocked by EWI

7.4.6 Thermal bypass and convective looping

Figure 45 (overleaf) shows an example of poor treatment of a ‘bell’ (protrusion at base of wall) in an existing wall. The cavity that is visible here is likely to induce thermal bypass or ‘convective looping’, as well as potential wind wash through openings in the base rail. Alternative treatment if using a rigid insulation board would be to parge coat the existing wall, or score the back of the insulation board in order to allow it flex into place against the existing wall. Figure 46 (overleaf) shows a similar problem, compounded by a large gap (over 15mm) due to undercutting of the adjacent board. This gap is larger than allowed by the supplier’s system specification.

Figure 45: Photograph showing gap behind insulation board due to a 'bell' in existing wall

Figure 46: Photograph showing gap behind insulation board due to a 'bell' in existing wall and poor butting of adjacent board

No instances of parge coating were observed and only two anecdotal reports were recorded. Most houses in Phases 2 and 3 had rough pebble-dashed walls prior to insulating -- often with significant surface variation. The results of boarding directly onto these walls were often a sizeable cavity behind the boards, as can be seen sealed with spray foam in Figure 47 (overleaf). As explained above, such a cavity will likely cause thermal losses due to convective looping, thermal bypass or wind wash.

Figure 47: Photograph showing gap behind EWI insulation board

7.4.7 Uninsulated areas

Without exception, specifiers allowed significant areas to remain uninsulated. This was generally ascribed to cost limitations. A less significant uninsulated area was understood as resultant from buildability challenges – either acknowledged by specifiers as too challenging to insulate, or created by installers in contradiction of specification.

Training Instructor 1 (P2) described this to experienced worker NVQ candidates as routine: "In EWI, we want 100% [coverage] but what they're doing is allowing 80% so they're allowing cold spots".

7.4.7.1 Wall-floor junction

No instances of insulation installed over the wall-floor junction were observed. Instead, insulation was extended to -- or close to -- the bottom of the existing render at or above DPC. Figure 48 and Figure 49 (overleaf) show a relatively common practice of starting the insulation roughly 50mm above the existing render line in order to avoid the unevenness or friability of existing render at this point.

Figure 48: Photograph showing uninsulated wall-floor junction

Figure 49: Photograph showing EWI system not covering wall-floor junction

Instead of leaving the bottom of render uninsulated, installers might have removed friable render or parge coated to obtain a more even surface before insulating. This was not observed in any instance. To eliminate a thermal bridge at the wall-floor junction, appropriate insulation material (e.g. XPS) would need to be placed against the foundation (requiring excavation). The failure to treat below DPC was attributed to financial limitations by numerous participants in all three phases.

7.4.7.2 Gas services -- uninsulated area

As shown in Section 7.4.1.2, areas around gas services were unilaterally left uninsulated. This resulted in poor aesthetics, but also a significant temperature gradient likely to present significant condensation risk (Figure 50, overleaf).

Figure 51 (overleaf) shows not only a large area around a gas meter left uninsulated, but a chase for the gas supply line (horizontal to the bottom left of the meter box), and another for a first-floor soil pipe (visible between yellow scaffold pipe and retaining wall). These areas could have been insulated if the services were relocated to the outside of the EWI system. As described already, this specification was routinely attributed to inadequate budget.

Figure 50: Photograph showing uninsulated area around gas meter

Figure 51: Photograph showing uninsulated wall area around gas meter, gas supply, and soil pipe.

7.4.7.3 Window headers

Where window headers laid directly under the top plate in existing construction (typical of some system builds), this area was left uninsulated in all observations (Figure 52, overleaf). This was explained by specifiers as due to two issues: the height of this space being less than the 200mm allowable minimum dimension for an insulation board; and headers were commonly steel or reinforced concrete which made installing pins prohibitively difficult.

Figure 52: Photograph showing uninsulated window header

7.4.7.4 Window and door reveals

To avoid obstructing existing windows and doors, insulating their reveals would require the employment of high performance insulants (e.g. aerogel or VIPs) or replacement with smaller windows or doors. Neither approach was recorded at any time. When asked, participants across all phases explained that these approaches were not financially feasible given project budgets.

7.4.7.5 Wall-ceiling junction

Contiguous insulation across the junction of the wall and top-floor ceiling joists along non-gable sides was not ensured in any recorded instance. Observations were made almost exclusively in single-measure retrofits. In a ‘whole house’ project, this area would routinely be insulated. In observed retrofits, this area was not surveyed and any continuity of insulation in this area would have been accidental.

7.5 Design and specification practice

Almost universally, primary contractors appeared to comply with stipulations from manufacturers and guarantors regarding specification of systems. For instance, appropriate renders were specified in areas of severe climate exposure, and fireproof systems specified where called for. Specifications produced by manufacturers are approved by agencies such as the BBA accepted by guarantee agencies. In turn, primary contractors adopt the specifications (in observation without any degree of revision) into proposed plans of work presented to the energy companies seeking to fund SWI (as part of programmes like CESP or ECO). Energy company technical staff in turn appeared to rely on the approval previously granted to the specification; no instances were recorded of energy companies rejecting proposed specifications.

As such, specification took place within a largely formalised framework. Beneath this, however, cost, contractual arrangements, personal preference, and a tendency to repeat prior approaches appeared to underlie the selection of materials and systems.

Specifications were often observed to differ from recommendations found in scientific literature. For instance, direct fixing EWI onto pebbledashed walls presented risk of thermal bypass (Section 2.5.2.1), or direct fixing of IWI without a VCL presented risk of condensation on the wall surface behind the insulation (Section 2.5.2.3). Similarly, temperature gradients present at areas of significant thermal bridging (e.g. uninsulated door and window reveals, wall-floor and wall-roof junctions) presented a high risk of condensation and associated problems. IWI specifications allowed for treatment of walls without removal of floor joists from uninsulated voids, thus creating a severe risk of condensation and degradation of structural members. Other instances of a gap between recommended best practice and specifications were less overtly problematic, but were likely to lead to marked implications for thermal performance. Manufacturers' specification guidance, for instance, made no reference to the implications for energy performance of decoupling thermal mass from conditioned spaces (Section 2.5.2.2).

In some instances, manufacturer specifications became 'internalised' as practice norms even where not necessarily relevant. 'Rules of thumb', such as providing expansion gaps in every 7 meters of run were often observed even if not warranted (e.g. synthetic renders were employed or elements interrupted contiguous distances of SWI).

The discrepancy between specifications and the risks of unintended consequences – particularly moisture ingress or vapour accumulation -- might have been due to the fact (as reported by CM1) that specifications were often based on standards in Germany, Austria or other countries where SWI had a more mature history, and from which products were commonly imported or adopted (and whose climates and construction traditions vary from the UK). CM1 felt that specifications were “not necessarily suitable for UK weather”.

Very few instances were recorded of failure to follow specifications (NB: specifications were often not reviewed during site inspections). One failure observed several times was phenolic boards installed with non-perforated base track.[52] In one case (P2), an installer was observed using non-fire retardant spray foam in close proximity to a boiler flue.

No retrofits employing ‘natural’ materials (e.g. cork, diatomite, straw) were recorded in any funded programme. One house insulated with cork board was observed in Phase 2; this was an owner-financed project.

It appears that at least some in industry are aware of the potential risks being propagated by specification practices. This was voiced in conversation with Industry Expert 1 and Managing Director (P3): IE1 was discussing the risks of moisture and noted a 19 per cent reduction in performance of SWI when moisture becomes “trapped in the system”. MD replied, “this is the [sort of] information we need… [we in industry need to know] where are the risks? How do I quantify the risks? How do I design them out?”. He later added, “to be honest, industry doesn’t want to know the science, [the SWI installation industry] want to know how to [design *out* the risks]”.

Against the scientific understanding of the principles of SWI performance (Section 2.5), the imperative of correct specification is clear. The findings presented here suggest divergence between best practice and actual practice of specification and that formal and informal knowledge transfer, cost

[52] Phenolic foam boards installed with non-perforated base track presents a risk of saturation of boards should water accumulate in the base track.

considerations, contractual arrangements, personal preference, and ‘inertia’ all shape current specification practices.

8 Results: phenomena understood to underlie quality and practices of installation and specification

8.1 Overview

The structure of presentation in this chapter and the rationale for this structure have been described at the beginning of the preceding chapter. The iterative process of developing questions, theory, conclusions and new questions that has already been described led to a heavy concentration of focus on the context of practices. Data which led to theoretical understandings of context (or contexts) are presented in this chapter.

This chapter presents data organised under the following themes:

- Financial cost and expenditure;
- Technology, constraints and conservatism in practices;
- Process management;
- Knowledge, understanding and ability;
- Influence of UK Government and public policy; and
- Drivers of insulation work.

Data related to the 'Drivers of insulation work' theme were closely related to the 'Influence of UK Government policy' theme. All data sorted under the former theme were either directly congruent with previously understood background to SWI retrofitting (as presented in Section 2.3) or could be considered a subset of the latter theme despite having been sorted separately during analysis. In the interest of concision, these are presented together with those sorted under the 'Influence of UK Government and public policy' theme in Section 8.7.

As in Chapter 7, it should be understood that data might be related to more than one theme; again, where this occurs it is noted. The order in which themes are presented does not convey ascribed significance; as described in Section7.2, a hierarchy of significance among themes is not possible and would be arbitrary. The order in which data are presented in this chapter responds to a logic in informing the reader about those mentioned earlier before reaching those mentioned later. For instance, it is useful to discuss data related to lack of training for managers after data related to management practices have been presented.

8.2 Characterisation of the observed retrofit industry

Early observation developed an impression of the structure and character of the SWI industry. Individual installers and micro installation enterprises were found to work in subcontracted relationships with large installation companies. These companies procured contracts with energy companies or local authorities (or were awarded contracts through intermediary agents) for delivery of large numbers of retrofits (typically 100-400 homes per contract). These installation companies -- even those with annual turnovers of many millions of pounds -- rarely directly employed installation staff; instead, they contracted with numerous micro-scale installer crews. As such, they were almost exclusively characterised as SMEs.

Individual homes within contracts were allocated by the companies to single crews (typically of two to four people); often one allocation was only succeeded by another upon completion of the first job. Crews progressed from one home to the next with little apparent meaningful interaction with other crews or the sort of 'cross pollination' of knowledge and practices found on larger construction works. An individual crew almost always consisted of long-term working partners and – whether a registered microenterprise business or a semi-formalised alliance of independent subcontractors – crews remained intact from one job to the next. Individual crews commonly shared not only equipment, transportation to work or job tasks (without crossover with other crews), but spent nearly all of their working time in relative isolation – despite typically working in close physical proximity to other crews in area-based projects. Together, crews (as formalised or semi-formalised entities) made up an effectively siloed and atomised organisational structure on large neighbourhood sites. Although they were overseen by the same site and contract management, and shared a site office and basic facilities with other crews, very little substantive and regular interaction existed in their daily working lives.

Installers of SWI were almost exclusively either 'upskilled' tradespeople with backgrounds in 'biblical trades' or (much less commonly) young people at the beginning of their working careers. With recent growth in the industry, an emergent population of workers for whom SWI installation is their first profession was found. Given the shifts in available SWI work over time, it is very difficult to ascertain how many installers exist in the UK at any given time.

A range of cultural and national backgrounds were found among installers in field research. The vast majority were UK nationals with social backgrounds typical of the broader construction industry. Some non-UK (EU) workers were observed, but such observation was rare. Management personnel and staff at manufacturers and system suppliers were without exception UK nationals, and rarely were found to have higher education degrees (with the common exception of surveyors and senior management figures).

8.3 Financial cost and expenditure

8.3.1 Cost to installation companies

All participants reported that SWI was commercially viable, but many installation managers discussed the need for budgetary prudence. In P3, the topic of budgetary constraint was raised over two dozen times in conversations with managers. The cost of materials was described by many as heavily influencing specification and practice. Financial constraint was often cited as a barrier to approaching specification differently, or allowing more time to be spent on works.

Typical material costs for EWI were reported by Quantity Surveyor Senior (P3) as ranging between £10 and £22/m^2; brick slips dramatically increased costs.[53] System Supply Business Manager (P2) argued cost was the dominant factor of specification across industry. He described that EPS comprised roughly 50 per cent of the EWI market, while phenolic foam and mineral wool about 25 per cent each; explaining, "because EPS is cheaper". He reported that phenolic foam was only used when its lower lambda value necessitated its use. He also reported that pebbledash is the preferred finish across the industry because it is "the cheapest".

Contract Manager 1 and QSS (P3) described that 'non-traditionals' were "much more profitable", this was explained as due to more "open meterage" (i.e. fewer obstructions and larger continuous planes), better access, "not having to get scaff lorries down windy lanes, et cetera".

With reference to enabling works, Training Instructor 1 (P2) explained that "they used to refabricate hand rails [mounted to exterior walls along ramps] and the like, now they just leave them in situ – it's too expensive otherwise". He also explained that due to cost, "nine times out of 10" EWI at gable ends was installed with a verge trim and silicone seal rather than roof extension.

Training Instructor 2, discussing 'bells' over window or door openings noted "we [in industry] should angle grind it out, but we don't. In theory

[53] The cost quoted by quantity surveyors in P3 Company was £21-27/m^2, not including corners which were three to four times as expensive per square metre. Contract Manager 2 described the installed cost of SWI with brick slips as £120/m^2.

everything should go behind [full thickness of insulation], but it doesn't – it's too expensive."

As explained in Section 7.4, external gas services were left in-situ rather than relocated outside EWI – widely ascribed to cost restriction. According to Trainer 1, "gas boxes – 99 out of 100 aren't moved". CM1 noted that these "used to be moved out" but were no longer. Energy Company Officer (P2) cited that this violated gas safety regulations[54] and argued that "these are not always met", explaining this as a "very serious issue". P3 Company often flaunted BT regulations and removed and reinstated telecom lines; paying BT to do this was seen as uneconomical.

Discerning between poor specification due to limited understanding of risks and due to financial constraint was often difficult. In IWI specification in P3 Company, for instance, while managers acknowledged that window reveals were left uninsulated due to cost (Figure 53), inappropriate specification of low-permeability insulants in direct contact with outside walls without a VCL was not attributed to cost. Managers claimed controlling vapour would have been prohibitively expensive; however it was unclear if they understood the risks their practice presented.

Figure 53: Photograph showing window reveal in IWI system. Note minimal clearance around existing window and lack of insulation installed in reveal.

[54] 26(9) Gas Safety (Installation and Use) Regulations 1998

Loss of materials was rarely recorded in P3 Company, although in Phases 2 and 3, reports were recorded of phenolic foam being destroyed in storage by exposure to rain. In P3 Company, it was reported that theft of lead (used on porch roofs, etc.) had forced the company to use alternative materials; this was the only reporting of loss of material to theft.

8.3.2 Individual pay

8.3.2.1 Rates

Pay for nearly all installers in P3 Company was standardised[55]. Almost all installers were paid by 'pricework' (also known as 'piecework'). The standard rate of pay to contractors for labour in the company was £16.50/m^2. This comprised:

- £4.50/m^2 boarding;
- £1/m^2 base rail and verge trim;
- £4/m^2 scrim;
- £1/m^2 beading and angles, soldier courses; and
- £6/m^2 pebbledash (significantly higher rates were paid for brick slip finishes).

This rate of pay was slightly lower than the apparent regional average of £17.50-£19/m^2.[56]

Only three installers – who had worked for the Company for roughly 20 years and were tasked with IWI – were on 'day rates'; presumably because the "old boys" had a predictable productivity, but it was also reported by CM1 that this was also a reward for loyalty.[57]

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[55] Discussion of pay in this section is primarily based on information collected during two days observing and assisting Quantity Surveyor Senior and Quantity Surveyor Recent Graduate in their regular work, which included producing cost reports, monitoring project expenses, and processing installer pay.

[56] New Company (P2) reported that they paid £5 to £10/m2 for pebbledashing labour 56 and £40/m2 for brick slip finishes. Training Instructor 1 (P2) suggested that £15 per hour was common for many junior boarders, and that £5.5 per m2 dry-fixed EWI for a crew was reasonable compensation. Other installers in Phase 2 reported being paid £4.50/m2 for wet-fix EWI and £3.50/m2 for dry-fix.

[57] IWI work was seen as easier, and also steadier due to lack of weather restrictions. According to one of the installers, the day rate was "probably because they make more money on IWI jobs".

One subcontractor, the Eastern Europeans' Boss, ran a large group of what were reported to be illegal workers (this was not confirmed and seemed inappropriate for discussion with Company administration). This crew was reportedly paid significantly below the legislated minimum wage; for reasons that were not clear, their 'boss' was paid £1/m^2 more than other subcontractors.

Energy Company Officer reported that his company considered typical compensation to companies as £47/m^2 for materials and £35/m^2 for labour. This suggests that principal contractors earned reasonable profit (see Section 8.3.1) after offsets for contract management costs and Builder's Work in Connection (BWIC) (i.e. enabling work).

QSS cited an average 20 per cent profit margin across all work. According to CM1, experienced workers might earn the Company £300 per day whereas new workers might produce just £30 profit (despite the rate of pay for 17-18 year-olds being just £2.65 per hour).

8.3.2.2 Implications

The pressure to maximise productivity was voiced by installers consistently across Phases 2 and 3. In many instances, slapdash work or poor attention to detail appeared to be directly related to this pressure. In order to maximise their earnings, installers 'on pricework' had a natural motivation to minimise time on each task. For instance, because windows and doors were relatively time-consuming (taking one hour each as a rule of thumb), they were often an area where poor workmanship could be found (see Section 7.4.3.1).

In P3 Company, site managers and enabling electricians, plumbers and carpenters commonly reported that they felt their rate of pay was inadequate. As one example, carpenters reported the £35 standard pay to remove and reinstall a garden gate was "ridiculously bad when you consider all you might wind up fiddling with".

In observation of IWI work by the installers on day rates, their workmanship was also extremely hurried (see Section 7.4.3). This might have been due to pressure from management, a sense of duty to maximise productivity, or pride in their speed. Indeed, the 3-person crew reported with obvious pride that insulating one side of a terraced house previously required 1.5 days but they had now only required a short day.

Inadequate compensation was not reported by any contract manager, surveyor or administrative member.

Sign-up Employee (P3) reported that the £3.50 he was paid per enlisted household was lower than he would like.[58] He described that as a result, he generally would not approach homeowners he perceived as difficult, or would not walk particularly long or steep approaches to homes if "easier doors" were available elsewhere.

8.3.3 Cost to trainers

The impact of cost on practices and on training and certification was ever-present. Trainer 2, for instance, often appeared rushed in running the course and persistently encouraged students to move quickly through practical exercises. He explained several times in private conversation that he felt the allocated time for training was inadequate and he wanted to ensure that students (with one week total practical training before being placed on site) had experience of all the tasks in the curriculum. Observation of training and certification is discussed further in Section 8.6

[58] This information was reported during a day helping Sign-up Employee "door knock" as he enlisted home owners in three neighbourhoods to participate in area-based ECO-funded projects.

8.4 Technology, constraints and conservatism in practices

8.4.1 Buildability and existing structures

Buildability challenges inherent in existing buildings were recorded throughout observations.

Services presented common challenges. Figure 54 shows an example which includes:

- security light;
- SVP pipe;
- gas meter box;
- satellite dish and cable;
- telephone cable;
- back boiler vent;
- water waste pipe;
- toilet overflow; and
- electricity supply.

Figure 54: Photograph showing multiple service mountings and penetrations, as well as projecting porch roof prior to EWI installation.

Other challenges were more idiosyncratic. Insulating over projecting porch roofs, small entrance porches, and conservatories presented common difficulties.

Projecting porch roofs – such as the cast in-situ roof shown in Figure 55 – cannot easily be treated. Probably the most sensible solution to eliminating this thermal bridge is to remove the original roof and reinstall a roof outside of the EWI. This was not observed practice; instead these elements were left in place in all observations.

Figure 55: Photograph showing projecting porch roof

P3 Company adopted a practice of offsetting EWI by 100mm to protect it from precipitation and soiling from splashing rain. Figure 56 (overleaf) shows soiling on a house without this offset (P2).

Figure 56: Photograph showing soiled area on EWI caused by splashing from porch roof

The offset employed by P3 Company shown in Figure 57 (overleaf) shows an example of poor workmanship: the underside of the insulation has not been supported by a section of base rail (as supplier specifications dictate).

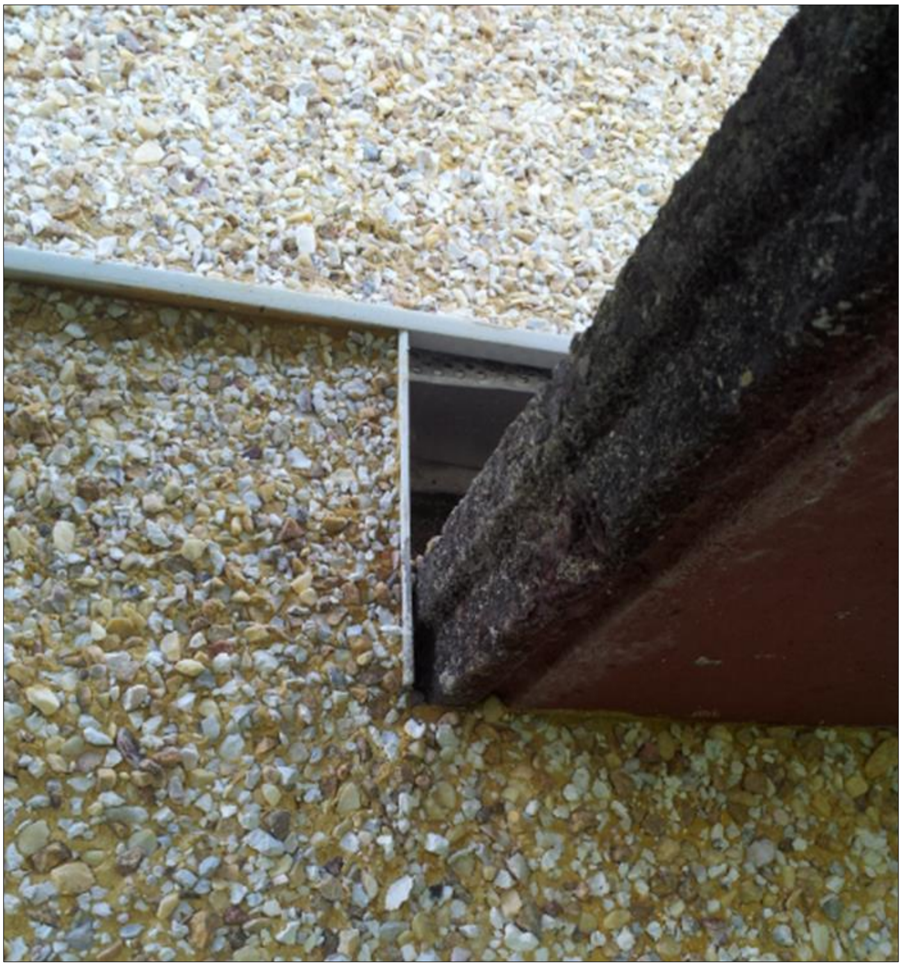


Figure 57: Photograph showing typical treatment of projecting porch roof

The entryway shown in Figure 58 (overleaf) provides an example of an outward-opening window adjacent to a surface ready for EWI installation.

Figure 58: Photograph showing problematic window and door position, seen prior to EWI installation

The entryway addition shown in Figure 59 (overleaf) provides an example of the solution unilaterally adopted in observed retrofits to the problem of outward-opening windows adjacent to EWI; an area of insulation has been removed to accommodate the window.

Figure 59: Photograph showing EWI cut away to accommodate outward-opening window

‘Work-arounds’ to existing windows and doors were required with remarkable frequency. Project budgets were universally reported as inadequate to allow for repositioning of windows and doors. Figure 60 (overleaf) shows a particularly difficult (though not unusual) challenge. Here, P3 Company has insulated around a bow window in its original position. Insulation has been chamfered to the sides and underneath the window. In this example, the opening window at top left remains functional; it was not uncommon to see windows blocked. Around the window’s roof, insulation has been offset. Flashing in these areas was particularly difficult given potential for damage to bay ceilings. No internal treatment of bay roofs was recorded and two installers reported that doing so would be costly and potentially disruptive to occupants; one installer discussed the risk of damaging interior finishes.

Figure 60: Photograph showing bow window left in situ

Window reveals were left untreated in all IWI observations (see Section 7.4.7.4). Figure 61 (overleaf) shows an example of a window abutting a party wall; here a significant thermal bridge has been created as the adjacent property has an uninsulated solid wall façade.

Figure 61: Photograph showing uninsulated window reveal and existing window with narrow clearance and abutting party wall

The difficulty of insulating window headers where they fell directly beneath a top plate was discussed in Section 7.4.7.3; an example is shown in Figure 62.

Figure 62: Photograph showing window header without insulation

Garden walls built against properties were common in many neighbourhoods. Walls were cut to allow continuity of EWI in just two P2 observations; in all other observations they were left in place and presented a thermal bridge to interior party wall junctions (Figure 63 and Figure 64, overleaf).

Figure 63: Photograph showing garden wall abutting original exterior wall

Figure 64: Second photograph showing garden wall abutting original exterior wall

Typically, observed projects had few access restrictions; this was because the vast majority of projects had been selected by installation companies based on cost-effectiveness and potential profit margin. Many factors could impede access; such as a lack of direct access to the rear of a house from roadside, adjacent structures, electrical hazards, plants or trees. Figure 65 (overleaf) shows one example from P2 which included some of these impediments to access.

Figure 65: Photograph showing restricted access around EWI installation

Observation of Structherm EWI[59] on BISF homes (P2) highlighted significant difficulty installing fixings; largely due to the friable substrate (BISF homes are nicknamed 'baked bean houses' by installers). The difficulty of achieving regular pinning patterns was underscored while working as an installer. This was particularly challenging in 'Wimpey' or similar constructions built of 'no fines' concrete as drilling into the substrate often resulted in crumbling. The installer is forced to use a smaller drill bit to achieve a 'tight pinning' and occasional 'blowing-out' is inevitable. Some installers were observed to ignore loose pins; preferring not to re-drill or sully the 'domino' pinning pattern, in part because of the potential for criticism from site management.

Spray application of render was observed once in New Company (P2); although this is common practice in other sectors of construction, this was the only observation in SWI. Several participants in P2 and P3 suggested that they recognised the significant labour-saving advantages of spray application but felt the equipment was prohibitively expensive.

[59] This product is an EPS board encased in a structural steel mesh.

In Training School 1 (P2), buildability was most often discussed in terms of IWI – this was surprising since the course was an EWI NVQ2 and there are many challenges related to EWI (described in this section). Trainer 1's comments, for instance, focused on system-build houses and minimal dimensions in bathrooms, working around staircases built against gable ends and services installed against walls.

8.4.2 Buildability and limitations of available technology

Buildability challenges were also observed with SWI materials. A rule of thumb among installers was that 'trimming out' (cutting and fixing the various pieces of trim around edges and openings) took an equal amount of time as 'boarding out' (cutting and fixing the insulation boards). While this time-intensity of trim work is broadly parallel to many aspects of construction work, in SWI, practical buildability and materials was a significant factor.

One example is corner bead trim, which must be clipped to the base rail during installation. It is widely considered 'fiddly' and it was remarkably common for improper installation to be visible. During post-completion inspections, managers often noted 'ugliness' and at times required reinstatement. This required removal of existing render and pebbledash.

Some installers (particularly in New Company [P2]) tended to avoid installing pins near verge trim as they feared striking and damaging it. Avoidance was allowed by many managers even though it clearly violated supplier specifications.

The application with base coat of mesh patches around windows and doors should be allowed to dry before meshing over with the primary mesh layer. This causes delays in work and many installers began primary meshing as soon as patching was completed. Adequate drying time (which is specified by manufacturers and suppliers) is required to achieve proper curing and full strength. As discussed elsewhere in this chapter, the propensity of insulants to absorb moisture on site and the vulnerability of adhesives and renders to incorrect application temperatures or surface preparation were buildability challenges which were often ignored by installers.

The lack of appropriate materials was also relevant to ancillary installation. Rainwater goods were a common example; most installers attach temporary rainwater goods to protect boards and new render from saturation, washing and blooming. Often these were jury-rigged goods; in several instances damage resulted.

Tools to improve workmanship, such as hot wires and toothless saws for cutting foam insulants were generally not employed due to lack of availability, cost or installer preference. Much more expensive tools such as an expansion gap cutter (£660) or higher quality drills (faster to use and less prone to installer error) were generally perceived as unaffordable.

8.4.2.1 Manufacturing faults

Mineral wool was the only insulant recorded as having faults in manufacturing with buildability implications. It occasionally contained clinker (from recycled board), which would bleed through render. This required boards to be inspected and discarded if containing clinker.

Poor consistency between batches of 'natural spar' used for pebbledashing required on-site mixing of bags or reliance on 'man-made spar'. Likewise, iron oxides in some spar resulted in post-completion 'rusting'.

8.4.2.2 Notable innovations

P3 Company had developed a simple welded square of base rail installed around vents before boarding in order to prevent inadvertent 'boarding over' of vents. This £20 component had enabled significant reductions in blocked vents. P3 Company had also developed a welded apex for verge trims which was considerably more robust than standard 'snip and bend' methods.

Community Interest Company (P2) had developed rainwater goods designed to eliminate the possibility of rainwater flowing behind EWI.

Other technologies were observed but with inconsistent uptake. Examples included 150mm toggles on which to hang radiators (eliminating the need for a timber pattress behind the fixing which is time-consuming to install, creates a thermal bridge, and creates a potential area for biological growth or decay), isolating caps for screw fixings (to protect from render and enable deconstruction) and standardised gas meter covers.

8.4.3 Conservatism

Many questions were asked of participants in each phase regarding technology selection. Rationale for product selection was routinely explained in terms of cost, ease of installation, and ready acceptance by project funders or administrators. It appeared that latent conservatism and lack of trust in untried products or approaches were highly significant factors but few participants referred to these directly.

Asked about factors in decisions to adopt innovative or new products in the retrofits they funded, an officer in Community Interest Company responded, "With new products, we're concerned with where the market is going. You know, what are the trends? Is there security? Is there a track record?"

No participants cited embodied carbon or any other elements of sustainability (environmental or otherwise) as drivers for technology selection in response to open-ended questions about selection factors (direct prompts about carbon or sustainability were not given).

8.5 Process management

8.5.1 Pathways to construction management

SWI installers were most commonly 'upskilled' plasterers who had transitioned to SWI work. This was often attributed to wider availability of employment in SWI.

Meanwhile, some managerial staff (except directors) had 'moved up' from working as installers. Others had been recruited from clerical roles in the industry. One installer ('John') complained that site managers lacked "coalface" understanding: "site management used to be a general foreman. That profession is gone – we don't even hear the word now do we?"

Managers universally reported learning management 'on the job' with little or no formal training. Although some had a background that positioned them to possess deep understanding of SWI work, all displayed limited understandings of scientific principles of SWI and formal management practices. These topics were frequently raised by the researcher during discussions and participant responses were coded; similarly, the topics emerged repeatedly as a theme during observation and analysis of unprompted behaviour and discussion.

The observed industry should not be characterised as devoid of formalised management practice. Some visible formalised elements of management practice are discussed in this section.

8.5.2 On-site supervision and monitoring

Senior management in all but one principal contract organisation indicated that they relied heavily on 'walk-arounds' and site managers to 'catch' poor practice and determine retroactive solutions (rework).

To a large extent, installers 'self-regulated' their work and their projects were inspected by site managers predominantly during brief periodic walk-arounds. Site managers relied on a variety of informal methods to evaluate work. A primary example of this was kerbside examination of pinning patterns; if pins were orderly, inspectors often assumed that workmanship was acceptable. Installers and managers alike described pinning as a signifier of care and attention. Contract Manager 2 described “being able to look quickly to find the nice tidy pattern”.

Less frequently, closer inspections were made. Although most companies (including P3 Company) attempted to document stage completions (e.g. boarding or scrimming), it was not common to observe inspections aligned to these completions.

Many instances were observed of practices which site or contract managers would have taken issue with had they been present. Quite often, a ‘cat and mouse’ game seemed to exist as installers (i.e. subcontractors or employees) sought to complete work as quickly as possible and to obscure any practices they knew might lead to criticism or disfavour from management. Similarly, other subcontractors (e.g. enabling, plumbers, electricians) appeared to work in this way. This pattern was exemplified in observation of an IWI job in Phase 3, in which three occurrences were recorded:

- the plumbers drained radiators carelessly and spilled a great amount of water into the ground and first floors, which ran into the floor voids;
- the home owner was allowed to conduct electrical work related to the project, which he volunteered to do after the electrical subcontractor failed to arrive. During this, a short circuit occurred and the circuit breaker was tripped; and
- the insulation installers did not remove vinyl wallpaper from any surfaces other than the window reveals, which were the only surfaces that would be visible at boarding completion (all insulated surfaces were wallpapered initially).

The mechanism’s limitations did not appear to be recognised by senior management, who generally blamed installers for poor practice. This was captured in one emblematic instance in which Contract Manager 1 (P3) remarked of the inadvertent covering of a gas flue during EWI installation (see Section 7.4.5.1), “it’s not a procedure problem, it’s a person problem – [some installer is] not following [best practice], you know”.

Industry Expert 1 (P1), New Company Contract Manager (P2) and Managing Director (P3) all pointed to the common occurrence of details in the final stages of work (e.g. sealing around satellite dishes or good practice in reinstating fixtures) found neglected at handover.

Only twice was a client-side inspector (i.e. clerk of works) observed on site and once a surveyor employed by a project insurer was observed inspecting works. Therefore, the predominant share of inspection was conducted by direct employees of the primary contractors.

8.5.3 Oversight and control

A tension was commonly discernible between managers and installers. Although relationships were overtly and generally friendly, it was evident that many installers resented the authority of managers to demand rework. The 'cat and mouse' game described above provides one signifier. Private derisive comments from installers toward site managers were not uncommon, though were only recorded from some installers; generally those observed to frequently receive criticism from managers.

A tension also existed between some site managers and Contract Manager 1 in P3 Company with regard to the regularity of inspections of retrofits in progress. CM1 consistently voiced that site managers needed to spend more time conducting inspections (he suggested one-half of their day); partly as a way of ensuring standards were maintained, and partly to ensure that installers were aware of being monitored. In confidence, most site managers reported voluntarily inadequate time for inspections. Many relied on rainy days (when installation was slower) to complete paperwork.

Given that 'control' of workmanship appeared to be perceived by managers as necessitating installers to 'feel' they were being watched, site managers did not appear to spend enough time inspecting work to control installation consistency.

Where jobs were 'condemned' due to poor practice and SWI needed to be replaced, P3 Company's typical procedure relatively lenient: the Company paid no additional labour but covered the cost of materials; if a particular subcontractor produced an unacceptable frequency of re-work, this arrangement was informally negotiated and the subcontractor would contribute toward material costs.

The theme of inadequate control of processes extended to communication between P3 Company and occupants. In time spent shadowing staff in P3 responsible for enlisting homeowners in area-based projects, Sign-up Manager and two sign-up employees displayed a relative ignorance of the particulars of SWI and functioned – in essence – as salespeople. This was reflected in the perception of others in the company who referred to these staff as "door-knockers" or "canvassers". The staff had no formal training in SWI and relied on 'popular' knowledge (Collins & Evans 2008) as they engaged with homeowners. Canvassers were trained as SAP assessors and Green Deal Assessors (GDAs) but this did not appear to prepare them to serve as a critical point of contact with occupants. According to Sign-up Manager, they were relatively well paid, with door-knockers earning salaries comparable or above what he saw as an industry standard for GDAs of £42,000. This suggested that appropriate incentive was available to enable the necessary training of staff.

8.5.4 Communication

Ineffective communication was a recurrent observation across settings in Phases 2 and 3. This was contrasted by some notably successful practices.

In coding, data most commonly associated with poor communication related to conflicting messages. One example came from Quality Manager (P3) who described discordance between practice guidance presented in accreditation systems, training curricula, and system provider instructions and noted that this often resulted in "layers of errors" as installers and managers were unsure which standard should be followed in a given situation. In another observation an experienced worker at Training College 1 discussed norms for window reveals, noting "that's the problem isn't it, you go to a different site and there's different rules and ways of doing things and everything".

Guidance for insulation around gas services was remarkably poorly understood. This often led to unsafe practices as described in Section 7.4.5.3. In the work (P2) shown in Figure 66 (overleaf), the area around the gas meter and supply line was left uninsulated until specification could be verified. In the meantime, the insulation had been skimmed and meshed, and this area later was 'pieced in' – creating extra work and an inefficient job process.

Figure 66: Photograph showing an interruption in workflow

NVQ training emphasised the centrality of Risk Assessment Method Statements (RAMS) to communication between installers and site managers. In NVQ assessment, RAMS is very often the only answer to questions which ask how installers should identify the installation procedure they ought to follow or the particular specification which is called for. Despite this, RAMS were never observed being read on any site and appeared to be posted in site offices as a matter of protocol only. When asked by the instructor in Training School 1, no experienced worker NVQ 2 candidate reported having seen a RAMS in the course of work.

Common forms of non-verbal communication included manufacturer's handling advice (Figure 67, overleaf) and postings in site offices (Figure 68, overleaf).

Figure 67: Photograph showing an example of non-verbal communication to installers from manufacturer of vacuum insulation panels

Figure 68: Photograph showing an example of non-verbal communication found in site office.

The use of visual aids was missing in the NVQ training courses which were observed. Training School 2 was planning to create crude mock-ups of EWI. By contrast, the BSEI (Coincident Phase, see Section 8.6.5.5) employed several useful mock-ups in teaching (Figure 69, overleaf).

Figure 69: Photograph showing an EWI mock-up teaching aid at the Building Sector Education Institute in Luxembourg

Communication between contractors and home owners was observed as alternately successful and poor. The primary contacts between the two parties in P3 Company were the tenant liaison officers (Section 8.5.7), sign-up employees and (less importantly) site managers.

Sign-up Employee (P3) demonstrated a comprehensive lack of understanding and reticence to communicate many of the fundamentals of SWI to homeowners. Although his role did not have direct involvement in delivery of SWI, his was the first point of contact with occupants. In one interaction, for instance, he cited a number of falsities: that the insulation was half the actual thickness; that insulation would extend to the ground; that over cills would be used; that brick slips could be selected at no additional cost; soldier courses beneath windows could be selected for all windows; that the render would not be harmed by cut grass or foot traffic; and that the EWI would be installed directly against the porch roof.

Some reports of complaints about misinformation from homeowners were recorded. Strategies to eliminate complication in communication were discussed a number of times between management and site managers and sign-up staff. One example of strategy was offering only four colours of pebbledash to residents (which could be used in combination on separate stories), and similar restrictions in detailing and trim.[60]

8.5.5 Systems of quality control

Rudimentary management practices were observed as dominant, with broad reliance on informal techniques. Some formalised elements of management practice were visible; for instance, risk and methods statements (RAMS) were universally available on site in compliance with health and safety norms and regulations. Their use in informing practice was widely ineffective (as described in Section 8.5.4).

The area-based scale of works appeared to be stimulating contractors to improve effectiveness in management. Without exception, management followed traditional quality control practices (last at the vanguard of practice in many sectors of industry several decades ago). Nevertheless, CESP and ECO (among other programmes) required inspection and documentation and this clearly had begun to nudge contractors toward formalised management practices.

Quality inspections in P3 Company, for instance, had recently evolved to include an inspect-and-display system akin to the proprietary Scafftag system used for scaffold safety inspection. The 'QA card' for each house was filled in during a sequence of inspections by site management – ostensibly to be made throughout the installation process. It served a complex function – as much a signifier of control (or agent of power) used to concretise management's authority, as it was a technically functional tool. Viewed another way, the card provided talking points, and so structured and enabled discussion

[60] Comments recorded about this strategy reflected not only an interest in 'keeping things simple', but also an opinion that it "improves the aesthetic of the neighbourhood", and reduced cost and waste.

between various actors on site. As a tool of construction management, however, it was unsophisticated and incapable of capturing the complexity of retrofitting all surfaces of the wall. Quality Assurance Officer (P3) recognised that the QA system being employed in the Company remained "mostly just tick boxes", and lamented that site managers were not following procedures in the spirit in which they were intended but were "just ticking [the QA cards]".

The QA cards were not translated into the appropriate Eastern European language for the subcontracted crew which did not understand English. Contract Manager 1 did ask the one crew member with relatively fluent English to translate the 'Safe Start' cards which were used to ensure health and safety norms were followed, but – despite these being introduced at the same time as the QA cards – he did not ask for any other documents to be translated. This appeared to be a missed opportunity to address poor communication between site managers and the non-English speaking crew.

In the year preceding observation, P3 Company had introduced a 'Quality Assurance Procedure System' inspection form to be used by site managers during regular inspection (Appendix E). This document was created by Quality Manager (in consultation with Contract Manager 1 and other management staff, understood to include Contract Manager 2, Company Director, Surveyor 1 and Surveyor 2.). The document was observed being used during a walk-around only once (when Contract Manager 1 was also on site). It was often referred to in conversation with Contract Manager 1, however – generally in a teasingly harassing tone with CM1 encouraging SMs to use the form. CM1 remarked on two occasions that it was a challenge to get the SMs to do this. SM1 and SM3 were both observed to complete the inspection form at their site office desks for several properties. This appeared to be a careless action in which the 'yes' field next to each criterion was ticked without reflection. The 'notes' field for each page was left blank. Although it is conceivable that this was based on certain knowledge of the actual condition of each job, it appeared in all instances that more rigorous inspections were not undertaken.

Community Interest Company (P2), by contrast, used a 'snagging app' as an effective means of managers tracking work with annotated photographs.

Rather than relying on sophisticated systems of QA, most managers in Phases 2 and 3 described their job as requiring a sense of ‘rhythm’. CM1 recognised that his company needed to improve its practices:

> You might be working on a 300-house contract but you’re not working on them all at one time. You need to get your arse end in line with your front end with QA you know. You need to get it all tightened down so that when a house is completed you can close it out in seven days and that house is finished then – you know - the QA, and it’s behind you then. It’s completed and you can go onto worrying about the next one.

One further effort to improve quality control was the ‘performance development review’ (PDR) introduced to P3 Company by a newly-hired management officer (Health and Safety Manager). HSM was tasked with ensuring health and safety and quality standards were being met. A document was produced explaining that the scheme “is available to all staff” and staff should receive progress reviews on a monthly basis. The scheme requirements are typical of most workplaces (i.e. reviews followed a ‘SMART’ model). CM 1, Quality Manager, and three site managers were all recorded in separate conversations indicating resentment toward “Healthy and Safety Manager”), using names such as “job’s worth”, “Mr. Clean”, and referring to his work as “he’s here to a job, but that’s it isn’t it – you just have keep your head down, keep your ducks in a row for when he’s around… when he comes up through the door, be ready with your paperwork”. Although the PDR scheme had existed for less than one year, indications were that it was not markedly effective and was being viewed as a formality by staff.

8.5.6 Health and safety

As typical of construction environments, health and safety were treated in all observed SWI sites with general adherence to professional norms and standards. Aspects of work were generally controlled in adherence with relevant statutory controls. These included: provision of site facilities (CDM 2007); scaffold safety (PASMA certificates); asbestos (Health and Safety Executive [HSE] regulations); grinding of substrate (hot works permit).

One site manager (P3) described health and safety “as far as my job’s concerned…[it is] the big thing”. CM1 emphasised health and safety as a paramount concern, often referring to the potential for action by the HSE and associated expenses.

Several actors in Phases 1 and 2 commented on the issue of gas safety and EWI. As discussed in Section 7.4.5.3, this appeared to be a valid concern. Energy Company Officer (P2), for instance, suggested that Approved Code of Practices (ACoPs) certification[61] ought to be made compulsory for installers. He also expressed concerns about frequent failure to observe "Gas Safe regulations…around internal corners and flue cut-outs" and suggested that contract management "has a key role to play in observation of [safety] issues" and compliance with regulations.

8.5.7 Dilapidation surveys and quantity surveying

Dilapidation surveys (or "preliminary surveys") were a way for companies to assess the condition of houses but also any potential obstacles to installation, and the requirements for enabling works, access, and similar logistical issues. In P3 Company, "dilaps" were conducted by dedicated staff known as tenant liaison officers (TLOs). TLOs had little if any background in construction or building science. Their tasks included meeting with occupants, getting disclaimers signed and notices issued, assessing and photographing the property, and liaising between occupants and site and contract managers regarding scheduling and particular concerns about each house.

Site Manager 3 and Tenant Liaison Officer 1 tasked the researcher several times with conducting dilaps independently. This provided an opportunity to understand the role and its challenges, and also showed the heavy workload that TLOs were under. It also conveyed an apparent perception that the task did not require special knowledge or training (or at least a readiness to allocate the task without first assessing the competence of the researcher). Despite this, both staff repeatedly stated that they found the job difficult and that it required capturing "lots and lots of details". Indeed, it was apparent that in addition to requiring an ability to manage the complexities of assessment while performing an array of administrative duties, it also necessitated a degree of knowledge to distinguish between various boiler and

[61] ACoPs certification requires completion of a 2-day training course in awareness of gas safety awareness and related procedures.

gas fire vents, plumbing penetrations, passive vents, and to recognise signs of damp or structural concerns. Through prolonged observation of TLOs, it appeared that they possessed some, but not all of these abilities.

A further day was spent with Quantity Surveyor Recent Graduate assisting him in 'measuring up' new work. On securing a new contract or when prospecting for new work, the Company would measure and record the dimensions of each house and note access necessities and any other special considerations. It was apparent that the administrative processes of TLOs might have been streamlined in order to allow more time to focus on the physical particulars of each property, and that the latter aspects of the job could logically have been handled by a QS during the building survey.

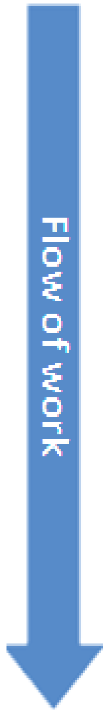
8.5.8 Logistics

Area-based projects presented management with logistical challenges in two areas: inventory control and alignment of work stages and responsible actors. The failure to manage projects optimally can have considerable expense in material losses, excess staffing costs, contract penalties, lost business and 'preliminaries' (e.g. site office and welfare facilities). Preliminaries alone on typical 200-350 house projects cost £2,000 per week and at typical 28 to 36 week duration, expenses are considerable.

8.5.8.1 Alignment of work stages and actors

Retrofitting required alignment of numerous contractors and employees in a succession of stages. This presented a variety of bottlenecks. For instance, site managers relied on enabling works contractors to work in ad hoc scheduling, which left other contractors complaining about irregularity of their work. Gas Safe contractors, to complete the CP12 process of certification needed to be present to commission and decommission each job. Site Manager 5 (P3) pointed to roofing and banding details between storeys as the most significant delays in work. Site Manger 2 cited managing the removal and reinstatement of SVPs as a "nightmare" since this often required the removal of a roof tile and risked rain ingress if the timing of work was faulty. Energy Company Officer (P2) pointed to clerks of work as common "snags in the process", explaining that aligning their inspections and approvals was difficult and that this often stymied project-flows. Contact Manager 1 (P3) summarised the difficulty of "timing" and "stacking up" of “work flow”, noting that every step added “a layer of expense” and necessitated additional management.

Figure 70 (overleaf) shows observed stages of work and corresponding actors – all of which requires alignment by managers and may be partly dependent on occupants to facilitate.



Work stage	Responsible actor
Neighbourhood survey	Quantity surveyor, management
Expression of interest	Sign-up staff/ Tenant liaison officer
Agreement	Management
Building survey (QS)	Quantity surveyor
Specification	Quantity surveyor, management
Dilapidation survey	Specialist staff
CP12 process (gas)	Gas Safe engineer
Scaffolding	Scaffold crew
Enabling works	Enabling contractor, electrician, plumber
Boarding	Insulation installer
Scrimming	Insulation installer
Top-coat render	Insulation installer
Reinstatement of services and fittings	Enabling contractor, electrician, plumber
Scaffold removal	Scaffold crew
Sign-off	Site manager

Figure 70: Work stages in EWI and corresponding responsible actors

8.5.8.2 Inventory and storage of materials

Inventory control in Phases 2 and 3 was managed ‘manually’. The ‘systems’ employed were largely responsive rather than predictive. Generally a site labourer would be tasked by a site manager to conduct a visual inspection of on-site stock, and from this new stock orders would be generated. Site Manager 5, Contract Manager 1 and Quality Assurance Officer (P3) viewed this as problematic because of its impact on cash flow and profit margins. They cited a £30,000 excess of materials on a previous site at the end of the project.

Inventory control in P3 Company’s main supply yard was managed by two older staff and based on several visits appeared to be very poorly managed.

Excess and untracked material in storage was routine and significant quantities of stock were left unprotected from weather and at risk of spoilage.

Poor practices of on-site material storage or a lack of knowledge about or knowledge transfer regarding storage guidelines were consistently observed. For instance, five instances were recorded across P2 and P3 of adhesive or render being used after storing below temperatures guidelines (5°C and rising during application). Were this occurrence known to warranty providers, the relevant warranties would become void. These instances appeared to occur with full knowledge of site management one morning while rendering was underway on a site, Site Manager 5, for instance, returned to the site office from checking stock in on-site storage containers and said “it’s fucking freezing out there like -- there’s fucking ice in there”. There was no insinuation that the temperature was a problem -- simply that it was unpleasant.

While in Training School 1, discussion of storage requirements covered only manual handling issues and made no reference to requirements for storage conditions.

An anecdote was relayed by Construction Waste Expert (P1) of a failure of an EWI installation in a high-rise building in Manchester due to saturation of phenolic foam due to poor storage and installation practice. Another report was recorded of a high-rise building with phenolic foam EWI which was condemned due to below-standard temperatures during installation. These were repeated and similar anecdotes were recorded in Phases 2 and 3.

8.6 Knowledge, understanding, skills and motivation

Themes of knowledge, understanding, skill and motivation emerged throughout observation of installers and installation contractors. These concepts are complex and are densely interrelated. The concepts and examples of related evidence are presented here. It must be acknowledged that the density of these concepts is such that more dedicated research is warranted. In this project, their significance has been undeniable and thus they are included – although with relative brevity -- in reporting of the research.

8.6.1 Evidence of knowledge and understanding

As described throughout this chapter, it was consistently evident that understanding of the potential for unintended consequences was limited among most installers. Similarly, many managerial staff and 'second tier' professionals displayed similar limitations. Despite this, a limited number of practitioners appeared to be quite aware of the vulnerabilities of EWI, even if this was not accompanied by a richness of scientific explanation. Quality Control Officer (P3), for instance, explained that the most common failures he sees are at the "roofline, windows, doors, satellite dishes and anywhere there's an edge or penetration"; however, QCO routinely made statements betraying a poor understanding of the behaviour of moisture in materials and building fabric.

Similarly, Training Instructor 1 (P2) displayed reasonable procedural knowledge accompanied by a dearth of understanding: "[ingress is] an issue especially on the pine end, EWI's gotta be completely watertight. Rockwool is okay because it lets water drain, lets it breath, it's permeable, it lets it seep"

Moisture risks were the most commonly cited risks, and few participants displayed a complete understanding of these risks. Throughout Phases 2 and 3, site and contract managers reported problems of installers blocking weep holes in window cills with EWI or under-cills. Often this action appeared rooted in ignorance. Training Instructor 2 (P3) cited this was a common occurrence and felt that many managers were not aware either of the occurrence or the risk of saturation it presented. He explained to apprentices his opinion that "Rockwool's okay – water will drop out". This misconception was echoed in opinions of many throughout Phases 2 and 3 that mineral wool was "breathable" or "could handle water" or would allow "water to run down the back [of insulation boards]". Site Manager 1 explained in discussion that "EWI has no condensation risk".

Limited understanding of principles of SWI and sustainability was particularly striking in NVQ instructors and assessors given their professional roles. This is discussed further in Section 8.6.5

8.6.2 Skills

It was often difficult to assess practical skill, particularly in P2 where observations of installers were generally more abbreviated than in P3. Discerning a lack of skill from carelessness, for instance required relatively prolonged observation.

Overall, it was apparent that most installers possessed considerable 'wet trades' skills; although poor workmanship was common this appeared most often to be a result of carelessness. Carpentry skills – relevant to cutting and fixing of boards, laying out, calculating required materials and trim work were much less consistent. Many installers seemed to possess limited 'carpentry' proficiency.

An interesting parallel came in observation of recruitment in P3 Company. Apprentices were recruited from a plastering course at a local training college and the local Job Centre.[62] Contract Manager 1 explained that the "ability to plaster is essential, chippie skills and et cetera isn't". CM1 made selection largely autonomously. CM1 explained his decisions were based on "a good feeling", but added that ownership of a car or proximity to a neighbour who works in the company (i.e. access to transport to site) were important criteria. He also made clear that 'attitude' was an essential criterion. No discussion addressed topics of aptitude or knowledge base, other than "experience laying on" or doing "yard work" (i.e. basic site labour).

[62] Four of five Job Centre applicants did not attend their scheduled interviews. This was explained as normal and due to the fact that Job Centre requires clients to sign up for interviews but attendance is not customary.

Company staff routinely described apprentices as “plasterers” and this reflected a lack of value for the carpentry-based skills necessary to achieve neat and continuous boarding (without thermal bridges or air or vapour routes from gaps) and correct trim and boundary pieces (important to finished appearance and to minimising stress on render and adhesive in the SWI system).

8.6.3 Legacy and entrenchment

Conveyance of tacit knowledge between installers was not observed to be fostered in formalised training structures. Instead, exchange of knowledge appeared to be characterised by ‘clustering’, as it occurred predominately between installers whose working or social lives brought them into regular contact (often appearing between several fellow installers who shared geographic location and a principle contracting organisation). Exchange of knowledge across the wider installer ‘community’ did not appear robust – for instance no evidence indicated facilitation by an organisational structure that fostered ‘cross-pollination’ on sites, regular training or professional development programmes, widely read industry magazines, or other drivers or interventions.. This appeared to be reflected in observation which recorded divergence in techniques, detailing solutions, and vocalised understandings between installation crews and across organisations.

Quality Manager (P3) described “systematic errors”, by which he meant the entrenchment of practices despite shifts in recommendations or requirements. He argued this was a recurrent problem in managing work.

Training School Manager (P3) highlighted a lack of “joined-up thinking” in P3 Company about training. He lamented “battle between education people and production” and complained that although senior managers wanted to improve practices (and were investing in training), production managers were “not yet really on board” with the agenda. He remarked:

> [Training is] about changing attitudes isn’t it – and the culture. [In Training School 2] we’re lucky the drive to change is coming from [senior management] aren’t we… to some people it’s all about pounds and pence isn’t it and nothing about anything else. But then I suppose it’s a business isn’t it. There’s a certain amount of both that’s got to be in it. But there’s certainly got to

> be some changes, some improvement, 'cause this culture's not sustainable.

Training Instructor 2 remarked that despite his attempts to train apprentices "properly", he was aware that entrenchment of practices was a significant obstacle once apprentices began to work on site. He explained:

> One of the lads come in this morning and said to me that he'd spoke to his dad last night who said that this whole thing we're doing is bullshit – that when you're out on site it's not how you do it. That when they're out on site there's no time, see. They just leave a big gap and foam it. But my argument is that's why they're here see, that's the whole point of getting them in here to teach them how to do things properly. And his dad's there saying there's no point taking the time to get things on the wall properly, you just leave big gaps and foam it. But that's exactly the point… that's what we're doing here – trying to change that culture.

8.6.4 Informal learning

Installers who entered industry prior to Green Deal and ECO requirements for certified installers were most likely to have received no formal training other than short health and safety courses or -- possibly -- manufacturers' product-specific training and certification courses ('carding') (generally one day in length or shorter) .

Discussion with Experienced Worker NVQ candidates (P2) highlighted that many had limited experience in parallel trades and felt they had received little support in learning the SWI trade. This discussion included comments such as "[new workers are] dumped on site and told either earn your money or fuck off"; "[new installers are] not really learning in the current system – they're falling by the wayside"; and "anyone can do the job, but it's all about overcoming your problems [with procedural learning and memorising tasks]".

Similarly, site managers almost exclusively had received no formal training other than health and safety or procedural knowledge. Contact Manager 1 (P3) explained that "cross-pollinating" of site managers – i.e. allowing staff to learn from each other by working together at times – was in important learning opportunity. This appeared to be the predominant approach to training managers in the Company. Industry Expert 1 (P1) argued that such training was a “benefit of the larger companies, but only…if it’s harnessed and optimised”.

8.6.5 Formal training

8.6.5.1 Overview

Formal training specific to SWI is limited to Level 2 NVQ qualification (almost all available courses are in EWI, some IWI training is available) and carding training provided by manufacturers. Carding is often required by guarantors or manufacturer’s warranty programmes.

Three routes to NVQ qualification are available:

- On-site Assessment and Training (OSAT) is typically a 2-day programme of testing and assessment, followed by short periodic on-site assessments which are generally conducted over the course of 12 weeks.
- The ‘Specialist Upskilling” programme -- which has assessment requirements similar to the Apprentice Route, but omits most training in skills and basic site knowledge -- is generally delivered over 12-15 days of classroom training, then on-site assessments over several months.
- Apprenticeship generally requires 2 years of combined classroom and ‘workshop’ training (typically one day per week) with on-site work and period assessment.

Guidance for eligibility and requirements for routes to NVQ certification are provided by the Construction Industry Training Board (CITB) (Appendix F).

No carding training was observed in full; observations here focus on NVQ Training as described in Section 6.6.

8.6.5.2 Role of policy/industry funding

Training was understood to be heavily influenced by government and industry funding. Training School Manager described that “grant scheme payments is what it’s all about… [external funding] is the only way to make money and make it all work”.

Similarly, the industry exerted a substantial influence on use of funding. Industry Group Training Representative explained that the focus of training programmes in IWI and EWI has been set by industry as 16-19-year-olds in construction colleges.

Nevertheless, numerous OSAT and upskilling programmes appeared to be running as installation contractors faced a heavy demand for qualified installers in order to comply with Green Deal and ECO requirements. At the time of observation, for instance, Training School 1 was drawing 60 per cent of its turnover from upskilling programmes.

Training School Manager (P3) reported that although considerable funding was available to support training, it was difficult to meet demand with adequate quality of instruction. He explained that to be able to devote adequate resources to training in insulating, he needed “to leave the training in wet trades to the colleges”. He added that many colleges were not engaged in SWI training and explained this was because:

- materials were too expensive;
- required space for mock-ups was too significant; and
- colleges perceived that the demand is not fixed or great enough and they preferred to focus on ‘biblical trades’.

8.6.5.3 NVQ training

Observation of two NVQ 2 courses included completing training in a two-week OSAT course and observing and assisting in delivery of a two-week apprenticeship route.

NVQ training focused predominantly on ‘site proficiency’ (e.g. procedural knowledge, health and safety, or management protocol) and offered little formal content relevant to unintended consequences.

Frequently, opportunities were missed during training to convey important concepts of SWI performance and associated risks of poor practice and instructors appeared to possess a limited understanding of important principles of SWI. For instance, in teaching students to use spray foam to fill gaps between boards (P2), no discussion addressed air-tightness or moisture movement. In another example (P3), students were instructed to ‘pack out’ some boards in order to obtain a flat surface (due to an earlier boarding mistake) (Figure 71, overleaf), yet there was no discussion of the potential for flexing or breaking of the board due to impact as a result of the space left behind the board, nor the potential for convective looping.

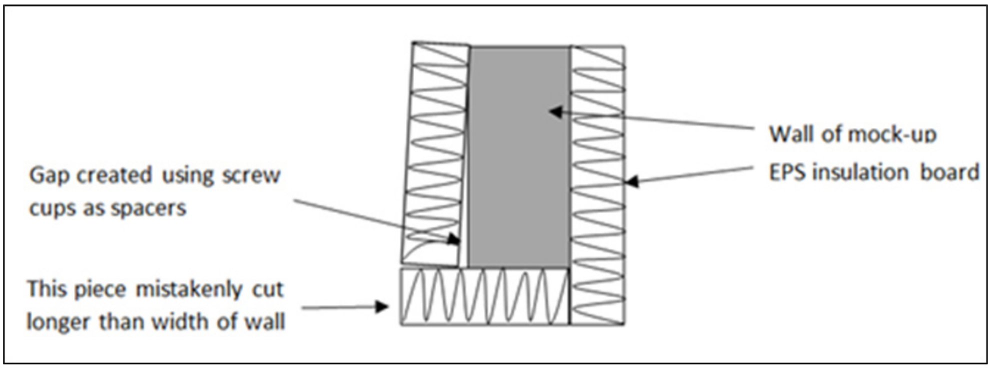


Figure 71: Drawing of observed poor practice in EWI installation training

Although NVQ2 instructors must be mentored, registered and hold the NVQ2 qualification, they are not required to hold any further qualification and the assessment of technical knowledge in NVQ2 is quite limited (it is primarily focused on procedural knowledge and health and safety).

Trainers frequently misstated information and appeared to possess limited understanding of the technical aspects of retrofitting. For instance, statements were recorded such as “Part L is about airtightness” (it pertains to energy loss), or “EPCs [Energy Performance Certificates] require thermal imaging” (they are generated from standardised modelling).

Investment in training by Training School 2 was considerable and its facilities were generally better-appointed that Training School 1. Trainers, however, were paid a relatively modest wage by Training School 2 and it was unclear if this undermined recruitment of more expert instructors. Training School Manager (P3) reported being “chuffed” about the £750 weekly pay to Training Instructor 2 and considered to be “value money”. He remarked, “I can’t believe we got away with that”.

Training Instructor 2 appeared at times to be eager to impress his managers by achieving key ‘sign-off- stages in skills development early in the training programme or by leading his students during skills practice and mock-up construction to be concerned with appearance rather than correct completion of each installation task. This occurred to the extent that he encouraged apprentices to cut corners during their skills practice sessions.

Neither of the observed training schools offered a realistic setting for practical training. Both had simplistic mock-ups or simple walls on which SWI could be installed. Both schools had square and plumb surfaces, which did not recreate the realities of most houses. Training School 2 had a plywood substrate to fix to which was far less challenging than typical substrate.

Training Instructor 1 (P2) explained that EWI best practice as taught in NVQ2 was “a million miles away from what’s on site”. He cited an example in which the void behind an EWI system created by a bell at the base of a wall ought to be “packed out” and sealed in order to ensure impact resistance and also to exclude nesting insects, but he declared “these types of things just never happen on site”.

Some observations of noteworthy practice were recorded. In Training School 2, a 7:1 ratio of apprentices to instructor enabled substantial one-to-one contact. Training Instructor 2 often presented actual specifications and cited real-life examples for students to work from during practical sessions. These sessions were well-received by the apprentices. Student 1 noted:

> I think this [week of workshop training] has done me a lot of good, like. Like they should make it so we’re doing two weeks of training just on boarding like. I mean [Day 7] is the first time I’m actually getting it. I mean the [dimension standards for boarding] and the setting out and everything – doing it the second time. Cause the first time it was all Student 2 doing it and my head was just swimming but this time I’m getting it like - like 100 per cent.

An observation on the first day of Training School 2 offered an unusual example of discussion of the broader contexts of SWI. Apprentices were provided with laptops and asked to answer questions such as: “what is Green Deal?”; “what is carbon saving for SWI?”; “what legislation is driving installations?”; and “what is a biomass boiler?”. Although this session displayed some misunderstandings of technical knowledge and relevant topics by staff[63], this was a rare moment of not just of addressing the sustainability agenda (albeit with severe limitation) but also introducing variation in pedagogical approach.

The apprentice route NVQ training observed in Training School 2 (P3) followed a programme which allowed limited time to present technical knowledge (registration-oriented activity was allocated more time). The majority of

[63] Comments included describing SWI work as “inherently green”, sustainability on job sites being equated to “switching off lights, not using standby and recycling your soda cans”, “green materials” described as “it’s about recycling” and misrepresenting the purpose of SAP assessment as “indicating sustainability”.

time was spent in practical sessions; the next most significant use of time was devoted to site proficiency knowledge. A schedule for the two-week training programme is shown in Appendix G.

8.6.5.4 Competency and abilities

Basic competencies of OSAT NVQ2 candidates appeared variable (P2). Most candidates were moderately adept at carpentry skills and generally adept with plastering. Understanding of principles of moisture transport in materials, or risks of unintended consequences in SWI appeared to be severely limited, although some basic knowledge (at times misconstrued) was held by most practitioners.

A number of statements made to students by Training Instructor 1, Training Instructor 2, Assessor 1 and Training School Manager (Phases 2 and 3) reflected a generally poor technical understanding and a tendency to misrepresent facts. Statements and observations included:

- "EPS can handle ingress, no problem" (no mention of risk to building fabric from trapped moisture);
- "They'll do thermal imaging… to determine the EPC;
- "SWI may make no real difference to [an EPC]";
- Complete misrepresentation of the Golden Rule in Green Deal;
- "Part L is about airtightness";
- Poor understanding of the concept of fuel poverty;
- Instructor suggests storing render on site under insulation to "keep it above temperature"; and
- Reporting that SAP Assessors must be qualified to "degree level in construction".

Training materials employed by instructors were limited and the few that were used contained were generally simplistic and included several recommendations for practices which were entirely out of line with best practices expounded by building scientists. Appendix H shows an example in which damp walls are not stipulated as unsuitable for SWI; instead, treating with algaecide is advised before SWI installation (no mention is made of the importance of allowing the damp fabric to dry before adding SWI).

Training School Manager remarked on the difficulty of getting knowledgeable apprentices from construction colleges, and offered an example of having to teach second-year plastering students the difference between types of drill bits, and how to space and centre hangings on a wall.

8.6.5.5 Model of good training programme

A visit to the Luxembourg Building Sector Education Institute (BSEI) (coincident research) training campus provided an example of advanced facilities for assembly and disassembly of SWI, VIPs, and many other energy refurbishment technologies, high-quality classroom spaces and a well-developed vocational training programme (see Figure 72). Like much of the training in the UK, the BSEI is funded through an industry levy.

Although the visit took place over just one afternoon, it provided a useful contrast to observations of the UK training industry. The BSEI appeared to offer a professional atmosphere and high quality facilities not found in observation of UK training. Observation was very short, but highlighted many of the deficiencies of space, amenities and professionalism that appeared to be missing in observed UK facilities and programmes. It also suggested that the industry levy mechanism is capable of providing adequate funding for training (a relative costing analysis was not conducted).

Figure 72: Luxembourg Building Sector Education Institute training facilities

8.6.6 Qualification assessment and certification

NVQ assessment requires answering so-called 'knowledge questions' and 'doing questions'. 'Witness statements' are accepted for 'doing questions' which enables students to avoid demonstrating skills to assessors.

Reflecting the NVQ curriculum, knowledge questions were largely focused on site proficiency described in Section 8.6.5. Examples of questions are provided in Appendix I.

NVQ candidates in both schools clearly struggled with written test questions. In Training School 1, the instructor frequently violated protocol and provided model answers which candidates copied verbatim -- often appearing not to understand their meaning.

The Construction Skills Learning Exercise (Psychometric Research & Development Ltd. n.d.) (Appendix J) is used by vocational training programmes to assess diagram interpretation and numerical reasoning. The exercise assesses relatively basic abilities, which an SWI installer would need to have in order to use materials and labour resources economically. In Training College 1, students were given the exercise the vast majority appeared to find the tasks highly difficult. Many students either refused to engage with the exercise or complained that it was far too advanced for them to complete. The response of the students (most of whom had been installing SWI for considerable periods of time before joining the course) -- although surprising in light of their trade background -- was perhaps predictable given the relatively limited schooling and professional backgrounds many reported having (typically reported as having no GCSEs, limited GCSEs above a 'C' mark, or having no or little sustained trade or professional experience).

The expectations of students conveyed by instructors were often remarkably low. Training Instructor 1 (P2) advised students that when selecting options for assessment (e.g. witness statements versus assessed 'doing questions') they should "do the easiest ones – only do those [i.e. select assessed questions] if necessary – you could always get a witness statement for the other". Anecdotes were related of peers who had "left their [training] pack in the loo" during on-site assessment and cheated the examination process by taking multiple toilet breaks per assessor visit.

Opinion was registered from several participants in Phases 1 and 2 that training colleges have a "money first, quality not" approach to training. Opinion of Training School 1 voiced by several members of industry (including a surveyor and a research consultant) registered after observation included was very derisive. One NVQ instructor noted:

> …these places are like fucking factories. It's like a conveyor belt. It's been quantity over quality. Because it's about money at the end of the day you know, isn't it. They just care about numbers. They just race them through here and as long as they make their money, well if they [installers] learn something on the way through that's great.

Training School 2, on the other hand, appeared to be generally well respected. Despite this, little difference in the quality of instruction was noted during observations.

Many report a negative perception of NVQ assessors. Training Instructor 2 for instance noted, "[NVQ assessors are] making a shambles of the whole qualification… You've got assessors who aren't qualified to be doing the assessments and the people who are in charge of managing them not qualified to do that."

NVQ Assessor (P2) described considerable frustration with his profession and his peers. Observation of his on-site assessment of OSAT candidates revealed considerable challenges as he needed to observe six students each complete a long series of tasks. He reported that unlike most NVQ assessors, he tried to "follow the rules". He explained that the pay for assessment was at most £250 per day, and more typically £350 per assessment, which notionally required two four-hour days of assessment (travel not covered). He asserted that many assessors would "go to site for 10 minutes then go back home and type it all up – write out a fucking story or whatever they want it to say". He added he felt assessors were commonly "imagining from that 15 minutes what they would've seen". He alleged that it was common practice among assessors to falsify assessment reports, have them signed by candidates or falsify signatures and "pocket the money". He felt that the pay was not reasonable, "you know you have to drive all the way to Manchester or wherever and if you have to stay over… and this should take you two days of work". He added:

> …so they'll do two in a week but actually only be on site for a couple of flying visits, then be at home for four days writing all their reports. Whereas me, if I've got to look at six guys, I'll actually put the time in on site to do that… They'll just get the guys to put their signature on the paperwork and then they'll [the assessors] just fill in the answers afterwards. It's a shambles. The whole thing's a fucking shambles and they're making a mockery of it. They're devaluing the whole thing and it's affecting the way people see the qualification.

He also reported feeling frustrated that his role in assessment was "to observe, not to teach" and added "you can't tell them what they're doing wrong", but added that "like everybody" he often offered guidance in order to ensure that candidates passed. He noted that no candidates failed. Assessment, he argued, offered only a snapshot of performance:

> Assessment is about ensuring that they can actually do things properly, not that they routinely do. I'm not interested in what they did yesterday. I'm not interested in what they're doing tomorrow. As far as I'm concerned that's site management's responsibility – that's the responsibility of the company.

8.6.7 Motivation

Data suggesting pride and motivation were found among the widest ranges of sites in field work (codes attached to notes from more than one-quarter of sites). As a theme of data, it is one of the hardest to write about since it is often recorded in a fleeting observation or comment. This research does not engage in careful conversation analysis, so where allusions or oblique references were made, these have been largely excluded from analysis.

8.6.7.1 Routes to SWI

Routes to working in SWI were consistent with many in UK construction. Training Instructor 1 argued to experienced worker candidates, "…it's why we're all in the building trades isn't it? We never did well at school. We struggle to learn things, at least at school. It's the only profession – well that I know anyway – that you can go into where don't need a degree but you can still pay the mortgage."

All seven apprentices in P3 Company were asked to explain why they had chosen SWI as a profession and universally they responded with explanations of change placement from their plastering college. Despite deep shortcomings in skills, many reported enjoying the challenge SWI presented. Some cited the possibility of variety in the work day which EWI afforded as compared to plastering. One reported that "there's great money in spreading [i.e. plastering] but all [plasterers] are on pain pills". This reflected a perception shared by most apprentices that EWI work is well-paid and less laborious or physically taxing than many other construction trades. Three referred to "chance" in explaining their routes to SWI; describing following their fathers into plastering and then being approached to apply for an "EWI job" while in college.

8.6.7.2 Pride and divisiveness

An emerging sense of professionalisation was observed periodically. Training Instructor 1, for instance, enthusiastically spoke of the role of 'EWIer'. Nevertheless, recorded instances of shared professional identity were rare.

Professional pride was observed to vary widely, but generally was limited. It was often apparent in relation to ability to produce 'coverage' (i.e. earn money quickly) or speed at installation -- but almost never related to high workmanship standards, knowledge, skill, or technical expertise. Occasional reference was made by first and second tier agents to greater or lesser frequency of call-backs among crews.

Despite earnings for installers being on balance equal to or above national averages for non-professionals, several strongly worded statements were recorded inferring that pay was inadequate. Training Instructor 1, for instance when asked to explain his opinion that installation quality in P3 Company was "shocking" (i.e. poor), replied "low wages, poor attitude, no quality management".

He added, however, that he attributed low morale to a "total inadequacy" in leadership and management of installers in the company. Experienced worker NVQ candidates (P2) referred to endemic poor quality across the industry, with one worker saying "[EWI is] falling off the wall – these companies are in fucking major trouble".

Numerous discussions were recorded which addressed the perceived vulnerability of installers to blame or financial liability in case of post-completion failure and a mistrust of the insurance and guarantee systems. A perception was common among installers that they would be 'fall guys' for poor practice and would be blamed for system failures. Installer Jim (P3) described that even when product or specification might be at fault, guarantors' inspectors would "find one small mistake" and use this to shift liability to installers. This was echoed by numerous installers, managers and other participants. NVQ Assessor (P2), for instance, noted "I don't care how good you are, you will miss something out, whether it's a bead or a fixing or a seal and that's what they're [manufacturer warranty] looking for – it's a way out, to throw it back at you." Training Instructor 1, warned students, "as soon as [homeowners] got any trouble, it's the surveyor and rep out to look…" adding that installers would be "hung out to dry" for "any missed pin…anything".

Similarly, an "us and them" or "blame" culture were lamented by several participants. In Training School 1, this was addressed directly by Trainer 1 and the School Owner, who both spoke to students of the downfalls of "the blame culture" on sites and asserted that "everyone has a lot to learn about this stuff… I don't care who they are, they don't know everything…".

NVQ Assessor 1 described in private conversation clashes of ego on sites and the detrimental impact these have on project quality, noting, "bad relationships cause bad work".

A similar, but distinct issue of divisiveness related to the presence of non-British crews on work sites in Phases 2 and 3. Disdain for the Eastern European crew in P3 was widespread (no research access to the crew was gained). Much of this was expressed in (unsubstantiated) flippant remarks about pay rates of £40 per day, working 7 days a week and 12 hours per day, and comments such as "all their money just [goes] back home". It was also, however, framed with regard to the crew's inconsistent work quality (observations were that it was generally poorer than average). This reflected a differentiation based on working conditions and work quality – surprising perhaps given the ubiquity in the Company of inconsistent work quality and complaints about low pay. In contrast to the common attitude, Contract Manager 1 explained that Eastern Europeans were valuable "because the industry is a lot more mature over there, they know what they're doing a lot more than these [UK] guys".

Finally, other more mundane forms of social stratification could be observed among installers in both Phases 2 and 3 with commonality to many construction sites and other work environments. Criteria for hierarchical ranking were clearly related to seniority, productivity, and amiability. Conversely, those who caused delays to the work of others or were seen to be sycophantic toward management were generally not favoured among their peers. In contrast to what some might expect, younger and less experienced workers were afforded considerable friendliness and acceptance on sites. Despite this, observations in both training courses recorded numerous instances of the young and inexperienced vocalising emotions indicating social unease due to appearing foolish or incompetent.

8.6.7.3 'Short-termism' and financial pressure

On most sites, the financial and temporal pressure that workers produce under was palpable. The (largely self-imposed) pressure principal contractors faced to maximise productivity within funding windows created a 'gold rush' mentality. This appeared to trickle down to sub-contractors who often worked feverishly to complete projects and 'stake claims' to available jobs. Meanwhile, the atmosphere was noted by many homeowners; many complained of shoddy workmanship, poor site practices and inconsiderate site management.

The so-called 'earn or learn dilemma', which discourages professionals from undertaking voluntary training was recorded consistently throughout observation.

In general, installation work was reasonably well-paid by comparison to other construction jobs; however in observation pay varied substantially between crews. Experienced and savvy crews were capable of earning two to three times average national incomes, while foreign workers were often working in exploitative conditions and apprentices working for well below National Minimum Wage.

One of the remarks that most poignantly reflected limited pride and a characterisation of industry workmanship as poor came from Assessor 1 while visiting NVQ2 candidates in Training School 2. He was discussing what he termed a legacy of "rampant" poor workmanship in the industry, and his uncertainty about the "safety" (i.e. propensity for unintended consequences) of SWI. He remarked, "I honestly believe that in the coming years companies are gonna be making a lot of money doing remedial works to the systems that have been installed". This was not said flippantly and was met with a generally embarrassed reaction from the students. He added that he had declined to have his own house insulated under CESP and "probably would never do it".

A close relationship between policy instruments and professional pride emerged during research and this was raised by participants during discussions with surprising frequency. Participants spoke of the impact of inconstancy in the programmes and of policy's prioritisation of "quantity over quality" (Section 7.3). CM1, described a general dismay in the profession about Green Deal and described that it offered "very little accountability" for workmanship. He added, "Green Deal is full of challenges. No one you'll talk to believes it's actually gonna come off -- at least not without major changes". In other conversations, he described the "roller coaster" of policy instruments and inconstancy of requirements and the impact this had on adopting systems of work in the Company. Site Manager 3 entered one conversation by exclaiming "as soon as we've got it [requirements for QA] pegged…they change it back up again".

8.6.7.4 Limited emphasis on training

Despite widespread acknowledgement from NVQ trainers and assessors that standards of workmanship and pride among installers were lamentable, NVQ Assessor 1, Trainer 1 and Trainer 2 were often recorded downplaying the importance of the certification/formal training process to NVQ candidates. Trainer 1, for instance, emphasised repeatedly to students that they ought to focus on passing the test (rather than engaging with the subject), encouraged rote memorisation of model answers (see Section 8.6.5) and made comments such as "you won't have to do it again" and "once you've got this [qualification], that's it, you're done".

In contrast, during other sessions, Trainer 1 and Trainer 2 were diligent in requiring careful practices during practical sessions. For instance, after observing irregular pinning patterns in students' work in Training School 2, students were required to remove pins and reinstall them more neatly (Figure 73, overleaf). This was a remarkable moment in observation as the response of the students was a profound increase in care and attention. This seemed to reflect a pride or respect for their work in contrast to relative indifference displayed during earlier stages. Other instances of taking pride in precision (i.e. craftsmanship) were observed in in both schools, particularly in response to prior critique by instructors.

Figure 73: Photograph showing NVQ 2 apprentices practicing 'domino' pinning in Training School 2

Overall, however, the general representation by participants of formal training was that it was something to be endured – if not dishonestly manipulated. This suggested that training norms were less than optimally effective not only due to limitations in content and delivery, but also in their failure to engage trainees.

8.7 Government policy

8.7.1 Policy as a trigger, waiting games and gold rushes

National energy and carbon policy described in Section 2.3 was found to be driving dramatic growth in retrofitting.

Energy Company Officer (P2) in discussing the doubling in the 'carbon price' against which their reduction obligations are assessed, expressed that "this is changing the landscape" in retrofitting and leading to a boom in SWI.

ECO brought about a dramatic expansion in SWI funding from energy companies. British Gas, for instance, expanded its funding from £350 million over three years under CESP to £1 billion per year under ECO. Despite this, according to Contract Manager 1, many of the shortfalls under CESP did not appear likely to be resolved under ECO. For instance, CESP finished one year late due to the poor achievement of the utilities in meeting their reduction targets (which many never met). CM1 reported that Ofgem had not fined any of the utilities for their poor performance and that he felt it was likely that the utilities would not be incentivised to invest in retrofits sufficiently to meet the ECO targets. CM1 estimated that ECO would run late just as CESP had.

Quality Manager (P3), in a discussion with CM1 and Site Manager 3, explained that P3 Company was "playing a waiting game" with the level of funding offered by utilities under ECO. He explained that as funding for SWI had increased over time under CESP, the presumption was that it would under ECO too.

Brokers often served as intermediaries between energy companies and installation principal contractors in area-based retrofits. Energy Company Officer explained that in his organisation decisions about which carbon reduction measure to fund (SWI or non-SWI), in what geographical area, and – in the case of SWI – what type of houses or materials would be involved, were "predominately about the bottom line". He explained that brokerages "dominate[d]" the SWI projects that his organisation was involved in, primarily because of the administrative simplicity they offered. He noted that this drove a 'low hanging fruit' scenario in which ratios of floor to wall area and avoidance of "hard-to-treats" determined which houses were insulated. QA Officer (P3) attributed the dominance of EWI in the SWI industry (roughly 90 per cent) as "almost entirely down to the policy".

Assessor 1 explained that retrofit funding mechanisms (e.g. CESP), which historically have run for relatively short fixed periods, create a "rush to certify" installers "before the deadline", by which he meant that the ability of companies to take on projects is limited by the number of certified installers they have. This, A1 explained, led to "pressure" on assessors and "cheating, fudging, and…poor assessment quality" and that assessors do "a huge amount of cutting corners". He explained that even without pressure from companies it was difficult to align schedules and get adequate time to see and assess each stage of the installation process. He explained that he considered himself and Trainer 2 to be "pedantic" about following assessment procedures, but implied that in the current climate it was often impossible to complete what he considered adequate assessment of skill and knowledge. He used "pedantic" again to describe the procedural requirements and deadlines in certification programmes.

8.7.2 Installation and specification standards in policy programmes

Policy programmes relied largely on PAS 2030 (British Standards Institution 2012) for control of specification for the installation. The Standard focuses on management of processes and control of quality throughout the phases of installation. By outlining consistent installation practices, the Standard targets better control of workmanship. PAS 2030 was consistently cited as a key standard for SWI work and the central control for installation process, and process management in the Green Deal programme.

8.7.3 Influence on supply chain

The impact of national policy on QA, particularly the dramatically increased requirements under ECO were clear throughout observation (see Section 8.5.5). CESP, in which Ofgem audited 5 per cent of retrofits for QA (selected by the contractee), did not – in the opinion of many, including P3 Company management – ensure meaningful QA. Energy Company Officer explained that his company required 7 per cent auditing to reduce liability and exposure to public dissatisfaction stemming from poor practices, and to ensure its QA obligations were met “by a healthy margin”. CESP required a 10-year guarantee on works, while ECO expanded this to a 25-year term. Contract Manager 1 (P3) described this as a “game changer” and noted that his company was developing more rigorous QA procedures in response to ECO.

In the opinion of Contract Manager 1, QA was “about the programme”, (i.e. the requirements of CESP and ECO). He argued that quality standards were not of great concern to homeowners, stating “people are just happy to get something for free – at the end of the day they’re getting something for nothing isn’t it? They’re getting their insulation and facelift to boot”. A similar phenomenon was highlighted by Community Interest Company Project Officer who argued that there was a “division in quality” between projects in public and private housing, with area-based projects in social housing correlating to the highest proportion of problems with quality.

Energy Company Officer described that problems in quality and the “customer journey” were becoming an increasing concern for his organisation. He described that his company’s technical monitoring department – although it maintained a paper trail, ensured PAS 2030 compliance, dealt with SAP and confirmed that systems and materials are BBA approved – was recognising that “mistakes do happen”. He added that this was confounded by an urgency of achieving compulsory carbon reductions from projects, and that his organisation needed to assess continually if SWI was a reliable approach to doing this. He spoke of problems with “stability in the supply chain” and remarked that the “ability to get [retrofits] done” remained a concern, adding “do they have the scaffold to get the work done? If they say they’re taking on another 500 houses, well is there enough scaffold in their local area to do that?”.

According to Energy Company Officer (P2), his organisation had a “natural preference for working with familiar contractors”; he explained “it’s human nature; it’s about relationships and familiarity”. His organisation operated a ‘stage-gate process’, wherein contractors were expected to provide details of properties, specifications, and their compliance procedure. He argued, “this makes it easy and really it’s what we need. We’re dealing with serious volume and we have no time for complications. If you say you can do it and I know you have a track record of doing it, then it’s a lot more likely to be a goer”.

Quantity Surveyor Head (P3) described considerable challenges in working on 'energy company work' (e.g. ECO and CESP) primarily due to payment schedules. It was typical he said of 'self-generated' energy company work to only receive payment on full completion. Payment on 'practical completion', conversely, made cash flow easier to manage. Contract Manager 1 (P3) described a scenario under CESP and previous programmes which would pay significantly at the 'weather-tight stage' of EWI retrofit, and then again at the 'scrimmed' (i.e. rendered) stage. Under CESP, a project could be 'opened' once scaffold had been erected (prior to retrofitting). In this situation, he described, companies would rush to erect scaffold (in order to 'claim' houses as their own), then sometimes wait many weeks before proceeding with works and only push to successive stages in order to claim payment for each milestone. Quantity Surveyor Head (P3) noted that because ECO only "pays upon [full] completion" there is "often a rush" to complete jobs. He argued that the ECO approach to payment meant that smaller companies "struggle" due to the difficulties of cash flow.

QSH reported that 'managed schemes' (i.e. not self-generated) were at least consistent in payment schedules. Local authorities were reported as often being "very slow to pay out". Across all arrangements, managing budgets was very difficult. "Held stock" on sites would not be covered by funders (so the company might be paid £20,000 for materials when £25,000 were required on site), and total costs in the company were approximately £200,000 per month so maintaining cost control was imperative. When asked about strategies for achieving this, QSH described that keeping all installation and enabling costs predictable was hugely important.

Finally, local government policies drive employment and training or regional workforces. Installation companies competing for contracts with local authorities generally must show that they will source a proportion of labour locally and train new installers. They are obliged to find cost-neutral options through grants or through college courses supported by Construction Industry Training Bureau (CITB) funding.

8.7.4 Siloed policies

In coincident research, observations were discussed in two sessions with a total of 12 technical and policy officers at DECC, DCLG and Ofgem. These discussions and discussion with ConstructionSkills Senior Officer (P1) and Industry Group Training Representative (P3) highlighted a shared perception that a problematic siloisation existed between government bodies, non-governmental bodies (NGBs) and industry groups responsible for developing training priorities and those who delivered training, assessment and maintained certification. All participants shared in the opinion that this resulted in often poorly aligned policies and programmes and deficient responses (or conflicting actions) between bodies. This was neatly described by DECC Technical Officer, who said "One of the challenges is that responsibility for the issue [of improving quality] falls between policies – and departments - and NGBs such as Ofgem – so it takes a bit more time to get everyone on board."

This siloisation appeared to extend to limitations in shared information and coordinated action. Industry Group Training Representative, for instance, pointed out that his organisation developed training in response to industry, which -- for instance -- might cause a lag between a shift in policy driving an increase in SWI or in requirements for certified installers, the industry highlighting a need for increased training or certification programmes, and the training and certification bodies being capable of responding.

Although these discussions were limited in scope, the topics discussed were evident 'on the ground' during observations in training programmes and industry.

8.7.5 Guarantee system

Product and system warranties are accredited by bodies such as the BBA and are contingent on appropriate specification and installation.[64] Warranties are relayed through system suppliers and the coverage of insurers is in part reliant on these warranties. The result is a complex system of liability.

[64] Most manufacturers and system suppliers provide 10-year warranties, with some offering 20-year warranties. One manufacturer was found which offered a much more significant 50-year warranty on its products.

Guarantees of workmanship (i.e. 'latent defect insurance) are provided by associations such as the Solid Wall Insulation Guarantee Association (SWIGA), which provide a form of collective insurance based on fees charged to installers who draw on their services.

Some guarantors routinely send auditors to site; while others offer a 'no contact' system wherein an installation company may simply registered each retrofitted house online.

Compliance with warranty and guarantee requirements was observed regularly during research in P3 Company. One inspection by an auditor employed by a guarantor was observed. This was in fulfilment of requirements for guarantee coverage in an ECO project. In this observation, the auditor arrived to a 250-house retrofit project to conduct one of five required inspections. He spent significantly less than one hour on site, during which he spent roughly 20 minutes in the site office comparing his notes on which properties were being insulated with Company records and receiving a progress update from the site manager (he did not audit QA documents). He then took a 10-minute walk across one part of the site and stopped very briefly at two pairs of neighbouring in-progress retrofits to conduct visual inspection (each lasting less than two minutes). During this inspection, he missed several installation faults that would be considered 'red flag problems' by Contract Manager 1. He explained that at the end of the project, he would visit again and report back any faults to the insurers.

The brevity of this auditing was relayed to Training Instructor 2 to assess his reaction (as he was a journeyman member of industry). He replied:

> See that's what it is isn't it? It's just fucking typical. What it should be is every house should have a number and should be photographed at every stage and every elevation and it should be tracked the whole way through. But at the moment, it's like they don't wanna know. It's all about the numbers and they just wanna crank things through. Really, if it's 60 houses, well that should be a week's work to inspect all them.

The auditor reported that in the remainder of his day, he needed to travel several hours to another site, than a further hour or two to another site. When asked, Site Manager 2 indicated that the duration and nature of the auditor's visit was typical.

8.8 Summary

This chapter and Chapter 7 have presented the reader with a broad range of data collected during field research. This has been presented in line with the categories of analysis that were developed through the coding and sorting process.

The following chapter contains a discussion of these results, which draws on the research context and review of literature presented in earlier chapters.

9 Discussion

9.1 Overview

This chapter presents interpretation of findings which draws on a variety of theory and research. Discussion delineates the implications of findings for quality in SWI retrofit and outlines opportunities for and obstacles to improving practice. Analysis is positioned against research from several themes, most notably: construction management, socio-technical and organisational studies, and organisational knowledge and learning. This research does not pursue an analysis drawn from a single body of theory. Rather, it proposes a variety of ways of looking at the observations and hopes that future research will build on these.

Discussion is presented in four sections. Firstly, the significance of this research for performance gaps and unintended consequences is discussed. Secondly, the concept of quality is reviewed and its relationship to results is considered. Thirdly, interpretation of results related to specification and installation practices is given; this relates most directly to Chapter 7 and earlier chapters. In the final section, the implications of findings in six areas are discussed; this calls on the evidence in Chapter 8, as well as context and literature presented in earlier chapters.

9.2 Performance gaps and unintended consequences

Avoiding unintended consequences in SWI retrofitting is reliant on appropriate specification and installation practice. On first approach, SWI retrofitting might seem a straightforward undertaking and one controlled by manufacturer specifications for material selection and installation procedure. In theory, it follows a systemised approach to 'design' and problems should be unlikely. Specifications are approved by bodies such as the BBA and accepted by guarantee agencies. Moreover, a proportion of installers are 'carded' by manufacturers, and increasingly (in compliance with programmes like ECO) many hold vocational qualification. Retrofit funding programmes create paper trails of evidence which document quality management and funders audit the work of principal contractors. On the face of things, layers of control ensure that retrofits are specified and installed in a safe and robust manner.

The findings of this research suggest that reality may be somewhat different.

Specification standards, while broadly appropriate, exhibit some important inconsistencies with scientific evidence about energy performance and hygrothermal behaviour. Moreover, although specifications provide detail solutions (and most manufacturers provide technical advice for atypical problems), observation documented an array of vulnerable (or aesthetically unpleasing) details allowed by approved specifications. The shortcomings of standards lie in part in their lack of specificity. More significantly, they encourage some practices that undermine energy performance and exacerbate risks (Section 2.5.4). This may be as simple as suggested in the recorded statement (Section 7.4.7) that specifications are based largely on non-UK countries where SWI has been employed more broadly. It may also be that knowledge exchange between those who produce and hold relevant scientific understandings of SWI and those who produce and provide specification has been inadequate. This is an area that warrants future research.

Observed installation provided adequate reason for concern that adherence to specification is inconsistent across industry. Furthermore, some problems with workmanship – while not outside specification – were clearly unacceptable. Installation practice is the veritable coalface of SWI. In installation, theoretical strategies to reduce energy demand are actually employed. The reduction of demand achieved by retrofits, and the avoidance of a host of unintended consequences, are in large part contingent on appropriate installation. Observed practices are described further in Section 9.4.

The control of specification and installation is reliant on effective construction management. Retrofits are currently employed in area-based projects and although this delivers significant efficiencies of scale, it also compounds some challenges in managing SWI delivery. The volume of activity and the risk of rapid propagation of shortcomings in installation or site management mean that optimised construction management is essential to controlling unintended consequences. Observations suggest that management practices are generally immature and on some sites highly inconsistent. Management personnel lacked formal training and were often incapable of fully managing the large projects they commanded. As a result, project managers routinely allowed (tacitly or explicitly) practices which deviated from best practices of specification. This was either due to failure to recognise divergent practice, lack of understanding of the potential consequences, or indifference. However it is defined, poor planning, oversight or ineffective management techniques routinely led to inconsistencies in build-quality and inefficient use of resources. Management practices are discussed further in Section 9.5.1.

Assurance that practices in the industry are appropriate and effective is (in theory) ensured in government policy programmes through auditing, manufacturers guarantees and latent defect insurance.

Requirements for auditing increased significantly between CESP and ECO. In light of the hundreds of millions of pounds spent on SWI over the past several years, it was surprising to observe that not only were the requirements for auditing only recently anything other than sparse, but auditing practices themselves were often cursory and at times, even dishonest (Section 8.7.5).

Guarantees and insurance provide a degree of security against unintended consequences which is particularly important in large scale projects under the energy company-funding mechanisms. The ability of manufacturer warranties and latent defect insurance (i.e. coverage of installation practice) to provide security of investment is contingent on several factors which this research suggests may not be present in current realities. Firstly, this relies on specifications which are robust; as described in this discussion, there is reason to question the appropriateness of current specification practice. Secondly, this relies on robust inspection of in-progress retrofits and systems employed by contractors to control quality. Finally, security of investment relies on adequate financial underwriting. If practices across industry mirror those observed in this research, there is a potential for very high rates of unintended consequences over the lifetime of retrofits. This presents doubt that underwriters (e.g. SWIGA) will be capable of providing adequate coverage for repairs and damages.

9.3 Emergence of the concept of quality

In light of high growth rates in SWI installations during the study term (Section 2.2.4), concern about propagation of performance gaps and unintended consequences is justified. The vast majority of solid wall homes and hard-to-treat cavity homes have not yet been insulated, but millions soon will be targeted by government policy. Clearly, there is great opportunity to learn lessons now before repeating inappropriate practices in future retrofits.

'Quality' has emerged as a description of a diversity of matters. In analysis, it has developed to include not just issues of build-quality such as conformity to specification, lack of aesthetic defect, and sound workmanship, but a wider set of issues as well. These have included, for instance, specification appropriate to considerations of hygrothermal behaviour, and of sustainability and resilience to climate change impacts. Quality has also been used to address the *process of* delivery -- such that it speaks to not just the management processes, but training, skills development, employment, and pride. As an ideal, quality represents robust physical form, robust conception of design and social benefit. In the entirety of a retrofit – from conception and design, through delivery and 'maintainability' – quality captures multi-faceted issues.

This signifies deeper complexities in the observations than a simple highlighting of poor workmanship. Observations suggest that there may be shortcomings in training and certification, policy instrumentation, management practices, financial underwriting of guarantees, technology and (not least) professional pride and social benefit. The full implications of observations – particularly if they are representative of realities across the broader industry – are significant not just to SWI installers, but also to a much wider range of actors.

The concept of performance gaps is widely applied in construction and engineering settings to denote disparity between intended and realised energy performance. Disparity between the ideal nature and character of SWI delivery and those which actually occur is termed here the 'quality gap'.

9.4 Understanding of practices

9.4.1 Specification

Section 8 highlighted a number of risks to energy and hygrothermal performance which were not reflected in manufacturers' specification guidance despite approval by BBA or similar bodies. The 'internalisation' of manufacturer's guidance described in that section suggests that these specifications often become modus operandi. Hence, their deficiencies are likely to remain unchecked by contractors or energy companies. It does not appear that, at any point in project development, in-depth surveying or design analysis are conducted.

A more robust approach to specification would examine atypical areas of individual projects to assess risks of unintended consequences. Ideally, this would not necessitate individual assessment of every house (e.g. in area-based system-build projects). Neither should this require re-examining specifications known to be acceptable. A more robust approach might, however, employ predictive models of condensation risk or biological growth (Section 2.5.2.3) to evaluate idiosyncrasies of a construction before detail solutions are developed. It is important that detail solutions are not created impromptu by installers or site managers who lack training and understanding of risk assessment. Numerous instances of this were described in Chapters 7 and 8.

Single-measure SWI retrofit makes ensuring continuity of insulation and vapour controls challenging, and is likely to cause discordance between required air exchange and available means of mechanical or natural ventilation. Single-measure specification may in fact be fundamentally flawed.

Moreover, the impacts of a changing climate do not appear to be accounted for in current specification practices, which seem largely uninformed by the likelihood in the UK for increases in winter and summer mean and maximum temperature and annual, winter and summer mean precipitation (Jenkins et al. 2009). Specifications must engage with the reality of future changes in climate.

Current specification practices have been shown – at least in some aspects – to be potentially problematic, and probably gravely problematic. It appears that additional layers of control are necessary to ensure that only robust designs are employed.

This may be as simple as ensuring that manufacturers and approval agencies (e.g. BBA) draw more strongly on knowledge transfer from the research community; it appears that a knowledge gap may exist here.

Qualified building surveyors might provide some degree of control to ensure that specifications are applied appropriately. For instance, they might be relied on to identify potential problems of existing damp, micro-climate or building performance. These professionals are already present (e.g. as ECO auditors); however they are tasked merely with assuring compliance to approved specifications. Moreover, as described in Section 8.7.5, these surveyors appear to have only fleeting engagement with projects and are not present at earlier stages of project planning.

Building control officers could provide checks that specifications were at least followed correctly. Observation indicated that officers are not trained on SWI specification, nor conduct meaningful inspections of area-based SWI projects. Their duty to enforce Workmanship Regulation 7 (Appendix B) might provide an opportunity to ensure better adherence to specifications.

The lack of available expertise to ensure that SWI design does not create problems of performance gaps and unintended consequences suggests that a change in how retrofits are delivered is needed. The potential for a new integrator of expertise is discussed further in Section 9.5.6.

Further discussion of specification of materials appears in Sections 9.5.5.

9.4.2 Installation

This thesis has presented evidence of a wide array of poor installation practices. There is a risk that by presenting these data, the reader may be given an impression of consistently poor practice without any sense of variation across observations. To be clear, not all observed practices presented cause for concern; it is the purpose of this thesis to convey observed practice and an analysis of this practice and so there has been an inclination to highlight remarkable events and examples. Because this was not a quantitative study, it is not possible to relay precisely the rate of poor installation practice which was observed. Nevertheless, although many examples of a ‘good’ standard could be found, on balance, poor practice was certainly omnipresent, and on some sites rampant. Significant defects of both aesthetic and functional character were very common (Section 7.4). This suggested that early anecdotal reports of concern about practices in SWI held merit.

Exploration of causal factors of problems with SWI practice confirmed many of the opinions registered by experts in Phase 1. These included that root causes lay in inadequate training, poor buildability, specification which did not account for localised climate and limited accountability for poor workmanship. Phases 2 and 3 have provided a much more nuanced understanding of the SWI landscape and have introduced a range of additional interpretations.

Aesthetic defects were observed predominantly in rendering and in detailing (Section 7.4.1). The assessment of an aesthetic defect is relatively straightforward; they are self-evident even to an untrained observer. The fact that defects of this type were pervasive across projects suggested deficiencies in construction management and quality control, and limitations in aptitude or motivation -- not only in installers but also managers, trainers, and project auditors (Section 8.6.7).

Poor workmanship created many examples of functional defects (Section 7.4). This included examples of:

- poor butting of insulation boards;
- improper fixing;
- system boundaries not adequately sealed or installed incorrectly;
- emergency gas shut-offs or ventilation openings inadvertently blocked;
- weep holes or capillary grooves in windows and cills compromised; and
- renders and adhesives applied or stored in unsuitable conditions.

Recognition of functional defects -- which often manifest in interstitial spaces in building fabric -- is somewhat more nebulous than recognition of aesthetic defects (e.g. pillowed render or uneven edges), and so requires a firm grounding in scientific understandings and best practice guidance. Through extensive observation it appeared that most second tier and nearly all first tier actors lacked adequate understanding to recognise some functional defects.

Nevertheless, it is difficult to justify failure to adhere to recommended guidance and to specifications. Proper storage conditions of render, for instance, are printed directly on containers. Fixing schedules or adhesive requirements for insulation boards are straightforward and communicated clearly, often on sheets packaged with boards. Some factors underlying functional defects may relate to limited understanding of the impacts of poor practice, but others appear more related to ineffective management and limited motivation to adhere to best practices.

The standards and guidance for controlling SWI appear limited and unfit for purpose. This finding has been reflected in a number of contexts presented in Chapter 8. PAS 2030 -- the overarching standard for installation and specification -- is remarkably unspecific in its language and this was recognised widely among research participants. The document offers only four pages guidance for each IWI and EWI (pp.66–70; 71–75), the content of which refers to requirements such as technical competencies (e.g. measured by Qualifications and Credit Framework [QCF] qualifications) or compliance with Building Regulations (e.g. in relation to workmanship, materials, or structural stability). PAS 2060 is currently in development and offers the potential to expand standardisation of SWI processes.

During write-up of this research, a review of evidence quoted a survey of more than 100 industry professionals in which no respondents reported agreement that existing installation standards were adequate (CoRE Fellowship 2015, p.4). Although this was published outside of the time period included in the field research and analysis, it provides important triangulation of these findings and so it is useful to highlight this recent publication. The review argues that existing standards – including PAS 2030 -- do not provide meaningful control of installation. The review notes (CoRE Fellowship 2015, p.3):

> Retrofit projects (including those involving SWI) typically go wrong at the corners, junctions, edges and interfaces … PAS 2030 is not fit for purpose –it concentrates not on the corners, junctions, edges and interfaces but on the uncoordinated installation of individual measures by separate installers who have been trained in 'silos', with little or no regard for how their work relates to what the next installer may be doing.

The delineation of "corners, junctions, edges and interfaces" made in this statement clearly reflects the state of knowledge about SWI principles reviewed in Section 2.5, as well as the some of the problems of siloisation pointed to in this research. Many of the vulnerabilities to workmanship highlighted in Chapter 7 have implications for the areas of potential weakness pointed to in this statement, but the critique of PAS 2030 could go further. Poor practices in fixing and adhesion, storage of materials, and aesthetic defects appear pervasive in industry but the PAS offers little if any meaningful guidance or control of these. Moreover, control of vapour in IWI and EWI, and considerations of impeded structural materials in cold areas in IWI are scarcely addressed in the standard yet present stark risks of poor installation practice.

In addition to the social and organisational factors of practices which have been highlighted, this work has also revealed complexities related to technology. The implications of this extend beyond any inherent limitations of technology, but also include compounded socio-technical phenomena. Discussion of limitations of technology, their agency and how this impacts the work of installers is presented in Section 9.5.5.2.

After the field research and iterative process of literature review and data analysis concluded, Ofgem released results of technical monitoring of ECO projects. This covered the programme period included in this research and included assessment of failure rates in SWI. As such, although the review was published after the literature review concluded, the report provides a further point of triangulation for this research. Monitoring by energy companies is required under ECO; this is based on a standard questionnaire, used to assess at least 5 per cent of measures in each quarter. Failed retrofits are categorised as either Type 1 – which "could moderately or signficantly reduce the ability…to deliver carbon or cost savings…" – or Type 2 – which present "little or no direct impact on carbon or cost savings…" (Ofgem 2015, p.2).

Results indicate that SWI and loft insulation had higher rates of failure than other measures; the rate for SWI was nearly 20 per cent (Figure 74).

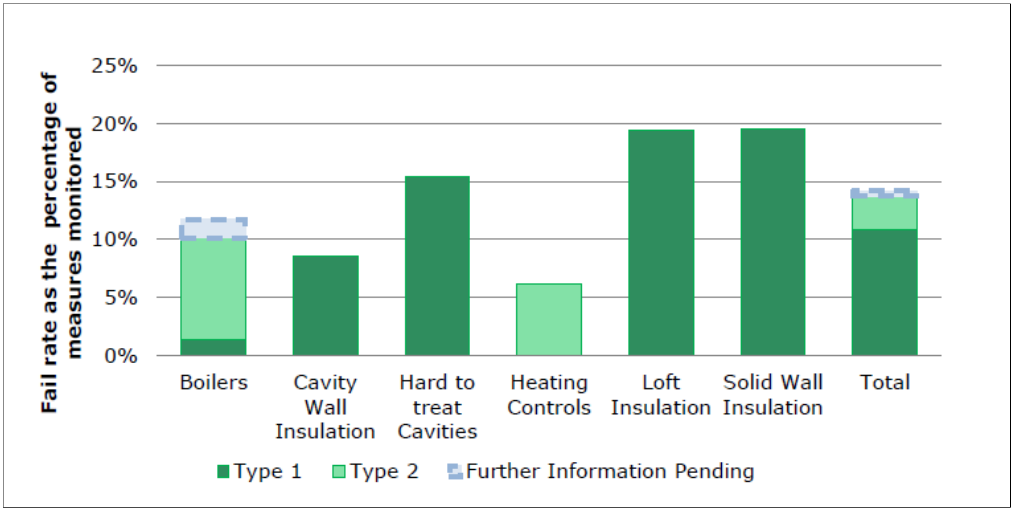


Figure 74: Fail rate as the percentage of measures monitored under ECO, 1 April - 30 June 2014 (Ofgem 2015, p.2). (Permission to reproduce original content granted by copyright holder)

The two most common failures in SWI related to EWI and were reported as (Ofgem 2015, p.4):

> "Has the finishing coat/cladding been applied as specified in the project plan and is the installation water tight? (Post installation question only)" (Type 1); and

> "Are the insulation boards bonded and/or anchored as specified in the project plan? (Post installation question only)" (Type 1).

These results certainly reinforce some of the findings of this research. There is justification, however, to question whether failures are underreported. The data collection method, which is based on questionnaire and visual inspection, is unlikely to capture many of the types of poor practices described in Chapter 7. Even assuming that inspection was rigorous enough to capture the myriad potential sources of failure (e.g. small areas of poorly adhered silicone), it would be impossible to verify many elements of installation through this means alone. Focused observation throughout the installation phase or a means of examining, testing or monitoring (destructive or non-destructive) post-completion would likely capture much higher rates of failure.

Regardless, these results underscore the significance of findings in this research which suggest that installation practices are inconsistent.

9.5 Implications of findings

9.5.1 Construction management

9.5.1.1 Management personnel and organisational structure

The site managers, contract managers, quality control officers and many directors included in the research had (with few exceptions) a career history in which they had 'moved up' from working as installers and thus had learned management 'on the job', and had received little or no formal training. This afforded them valuable practical knowledge and the ability to respond to many installer practices with an understanding of entangled tacit knowledge. On balance, however, those in management positions displayed little sophisticated expertise in construction management.

Organisational structures in installation companies varied considerably with the size of company (as assessed by total number of employees). At their most advanced (such as in P3 Company), organisation followed a conventional corporate configuration. Smaller organisations (e.g. New Company), deployed site managers and contract managers but these personnel appeared less capable of controlling day-to-day installation work – generally because of perceived lack of authority from installers, or limitations simply inherent in limited numbers of management personnel.

The fact that many management personnel had received little if any formal training in construction management (and were themselves often former journeymen installers with prior background limited to plastering work) offers some explanation as to why the legacy of mistakes which has plagued the industry historically appears to be perpetuated in current practice.

9.5.1.2 Management practices

In many ways, SWI installation appeared in observation to be a system of poor production quality. The few controls on installation that existed were frequently inadequate and the alignment of support to improve it -- the counteraction to control mechanisms – was equally weak. In fairness, SWI remains a nascent area of the construction industry.

SWI retrofitting, like most aspects of refurbishment, is inherently an unpredictable endeavour. Systems of management must control and respond to this unpredictability. Specifications are potentially an important 'check valve' in SWI, but poor planning and oversight of their realisation will propagate risks of underperformance and unintended consequences.

Construction management practices reflect the character of the SWI industry, which is generally comprised of micro-enterprises employing minimally-trained installers. As observed elsewhere in the RMI sector, SWI construction management was witnessed to be generally rudimentary. Senior management in all but one principal contract organisation indicated that they rely heavily on walk-arounds and site managers to catch poor practice and determine retroactive solutions (rework). A heavy reliance on walk-arounds, post-construction inspection, and unsophisticated techniques was correlated to high rates of rework, generally poor detailing, and loss of construction efficiency. Models of management based on TQM principles appear to be absent from the SWI industry and none were recorded in this research. To whatever extent other construction sectors have succeeded in advancing management practice, there is essentially no indication that SWI refurbishment has benefitted from either 'trickle-down' or cross-fertilisation of vanguard practices.

These strategies also appeared to cause undue antagonistic relationships between managers and some (but not most) installers. The 'cat and mouse' mentality (Sections 8.5.3 and 8.5.4) increased rather than decreased the quality gap. Improved management practices can serve to forge common identity, pride and ethos. Effective management is built on better 'systems of work', but it also has important significance to identity constructs, organizational and personal communication, shared aspirations and ethos, unified effort and professional pride. It should strive to inspire Sennett's (2009) 'obsessional energy'. The QA Card system (Section 8.5.5) has been described as functionally ineffective. As an instrument of hierarchical power, it provides an example of poor and antagonistic relationships (cf. Fryer & Fryer's 2004 "new Ps of management) and the obstruction of Lavender's (1996) "close, trusting and non-confrontational relationships" necessary for effective management.

Loosely formalised and primitive forms of management are clearly not passing the 'fit for purpose' test. Even attempts to improve the structure of traditional inspection-based approaches – which were last at the vanguard of management practice several decades ago -- are routinely failing the SWI industry as it strives to improve 'quality'. The newly-formalised site management inspections in P3 Company, for instance, were frequently ineffective. The tick-box inspect-and-display system was intended to be completed during inspection but site managers routinely disregarded protocol and completed the cards after (or without) walk-around inspection. Even honest adherence to this system would not go far enough. This form of management represents the lowest form of evolution of practice.

Principal contractors appear to be failing repeatedly not just at controlling the unpredictability inherent in refurbishment work and creating open relationships with installers, but are even failing at controlling the most routine elements of SWI projects. Advanced construction management would control processes much more tightly and likely reduce antagonism, which would improve knowledge exchange, motivation and working relationships.

Processes oriented toward continuous improvement, such as benchmarking for best practice, or achievements of competitors (Fryer & Fryer 2004), were rarely -- if ever --observed. If the evolution from inspection to quality control is to be realised, and in fact if the rejection of tolerance for errors that is integral to TQM is even to be approached, then management practices will need to become markedly more sophisticated.

Limited effectiveness in management did not appear to be recognised by senior managers, despite concerning frequency of considerable safety risks (Section 7.4.5) and rampant poor practices.

This suggests that managers are either unaware of the quality gap which is occurring, do not understand the importance of this gap, are indifferent to it, or lack the knowledge or ability to address it. Rectifying this will require developing training programmes for SWI managers, surveyors and other Tier 2 actors. It will also rely on the same mechanisms of improving inter- and intra-organisational knowledge exchange, motivation, and technology transfer described elsewhere in this section.

Against Winch's (2002) description of 'quality of realisation' as management which achieves procedural improvement (Section 4.2), 'quality' in SWI management appears low, with generally immature management practices with no clear trend toward improvement. Latham's (1994) well-known critique remains deeply relevant in construction and no less so in SWI today.

The industry must continue to pursue progressive action and adoption of best (if not vanguard) construction management practice. This is a colossal challenge.

9.5.1.3 Obstacles to change

SWI construction management appears shaped by a variety of forces: its inherited legacy, dependence on instruments of government policy, reliance on outside (i.e. not SWI) training and certification organisations, regulatory frameworks, technology and supply chains, and internal structure are all significant obstacles to change. Moreover, atomisation of sites (and the likely correlation with siloisation of professionals due to geographic distance) presents a barrier to change unless structured approaches to overcoming this are employed.

Clearly, inertia, resistance and adequate investment will be obstacles to introducing this change.

9.5.1.4 Opportunities for improvement

The first step in overcoming this will be recognition across all areas that a problem exists.

Overcoming resistance may benefit from previous normalisation of some constructs such as RAMS, health and safety regulations, of site hierarchy. These offer the real possibility that further formal mechanisms would encounter less resistance than might be feared in other areas of change.

Management will benefit from investment in formal training (of first and second tier actors) and in knowledge management strategies. This offers a path from primitive to advanced quality management. BRE has been considering introducing a NVQ Level 4 qualification beyond their current NVQ 3 in ‘site sustainability management’. This may expand the current focus on new-build management to include refurbishment and retrofit. This would be a first step, but clearly many more layers of training and knowledge exchange are needed.

Standards and guidance tools, as elsewhere in SWI, are in short supply. PAS 2030, has been described elsewhere (Section 8.7.3) as wholly inadequate to controlling SWI installation and specification and does even less to offer structure for management.

The recent review from the Zero Carbon Hub (2014, p.5) cited in earlier chapters was published shortly after the conclusion of field research. Its findings echo this research, as it argues "Site Quality Assurance procedures prioritise other issues above energy performance; this increases the risk of improperly fitted insulation, incorrectly installed services and thermal junction detailing different to the intended design".

This leaves a dearth of frameworks or benchmarks to ensure management's effectiveness.

Technology may have some contribution to make here. In a meeting with Managing Director, Business Director and Industry Expert (P3), the possibility of adopting the PDA-based tool which was used by Green Deal Assessors (based on yes/no questions) for use in SWI surveys was discussed. The camera phone snagging app system employed by Community Interest Company provides another model (Section 8.5.5). Investing in technology that will assist managing construction is long overdue.

The fact that SWI installations are likely to continue to be driven by policy instruments offers the opportunity to exert concerted influence on construction management practices. Policy offers the most powerful lever for change as has been demonstrated by the shifts in management practice it has already driven.

As ECO required documentation of every retrofit rather than the small subsample required by CESP, it clearly stimulated increased rigour in management practices. Successive policy-driven programmes should continue in the track of ECO to introduce new requirements for auditing and documentation of management. ECO mechanisms made significant impact on the ground, but observation suggests they did not go nearly far enough to effect necessary improvements in management. Making the leap from the basic paper trail required in ECO to documentation of each stage is a first step. Successive improvements should seek ultimately to harness TQM and advanced supply chain management principles.

The need for improvement in construction management is clear. Some progressive influence has been made by CESP and more so by ECO in the requirement these programmes make for evidenced site inspection, paper trails, and regular auditing. But evidence presented in this research brings to light that these requirements do not go far enough; numerous instances of poor quality 'slipping through the cracks' were reported. More comprehensive requirements are needed in future iterations of policy instruments.

An alignment of policy could drive changes in management as well the training and support necessary to bridge the gap in current and desirable practices.

The area-based scale at which a great deal of SWI work is now undertaken demands effective approaches to process management (be they formal or informal). This scale is conducive to efficient management practice due to the practical advantages of localised sites and higher densities of work processes. This, however, is balanced by dangers of immature processes of management failing to stem proliferation of quality gaps. Effective management will ensure not just efficient deployment of resources, but minimisation of risks.

9.5.2 Knowledge, understanding and learning

9.5.2.1 Reflection on findings

Significant doubts developed about levels of appropriate competency and technical knowledge across observations. Certainly, the effectiveness of formal training programmes must be questioned in light of this. Equally, observation also suggested that pathways of informal learning were limited by the nature of the SWI work-world and the relative absence of knowledgeable thought leaders.

These concerns were triangulated once again by the CoRE Fellowship review which was published after the literature review and field research were completed (Section 9.4.2). The review argues that (CoRE Fellowship 2015, p.3):

> A lack of adequately educated tradespeople and construction professionals was identified as a major barrier to successful retrofit. There is a lack of established best-practice, and mainstream training within the sector is considered to only reinforce the silos of expertise that typify traditional construction.

A closer understanding of the dynamics of construction knowledge exchange can be informed by the distinctions between 'tacit' and 'explicit' knowledge made by Nonaka and Takeuchi (1995) and Collins and Evans (2008). These terms distinguish 'know-how' knowledge from 'know-that' knowledge (Robinson, et al. 2005). This dichotomy is important to conceptualizing the pathways for exchanging knowledge relevant to quality in SWI.

We should understand that SWI installers and managers need not just 'knowing how' to carry out retrofits, but also 'knowing that' knowledge (which might equally be termed 'knowing why'). If professionals do not understand the fundamentals of science on which mitigation of unintended consequences rely, they cannot be expected to deliver quality SWI retrofits. This does not necessitate impossibly high standards of training or unrealistic expectations of installers. Carpenters, for instance, understand that boards can 'cup' (know-that) and that this is a function of the direction of growth rings in a board (know-that); they understand that to mitigate cupping risk they must fit and fix boards accordingly (know-how), but they also understand that cupping is the result of changes in humidity affecting shrinkage in fibre within rings (know-why), which enables them to avoid humid storage conditions that would damage their materials. Similarly, SWI installers must not just 'know that' they should provide robust controls for moisture, but they must possess a basic informed understanding of moisture risk ('know why').

9.5.2.2 Formal training

There were clear deficiencies in the observed formal training programmes. NVQ 2 appears to ensure only that very basic standards of competency are held. The emphasis in NVQ training on 'site proficiency' (Section 8.6.5) was not accompanied by meaningful engagement with basic scientific understandings or principles of SWI, which installers need in order to identify and mitigate risks. Likewise, carding training is limited to short training sessions focused on installation procedure. Hence, practitioners may be taught 'how' (with or without success), but are not taught 'why'.

Trainers often displayed poor understanding of fundamental concepts. Training materials, meanwhile, appeared basic and often contained poor information or misrepresentations of scientific understandings of SWI principles. The cycle of installers training installers may be generally suitable for teaching essential skills but does little to deliver much-needed knowledge and skills advancement.

Vocational training is often conceptualised as skills-based formal instruction. This, however, is a simplistic apprehension of the training many tradespeople – certainly those in SWI – require in order to function optimally in their work. To prepare SWI professionals to deliver robust retrofits with minimised risks of unintended consequences requires that they develop a working understanding of these risks and an ability to respond to complexities and solve problems autonomously. Although many tasks are performed by vocational tradespeople in the absence of (and without the need for) critical thought, to ascribe tradespeople with no capacity or need for critical thought is woefully unconsidered.

The current system of training and certifying SWI installers seems to treat their role as essentially that of automatons. It is facilitating neither the understandings of *what* best practices are recommended, nor *why* they are delineated as they are. This creates propensity for deliberate (if ignorant) and inadvertent poor practice. The reality as reported in observation is that installers and managers (most of whom 'learned management' by 'moving up' from installation work) create detailing solutions, engage in problem-solving, and are, in essence, responsible for performing intelligent risk-minimisation decisions in the process of deploying SWI.

SWI training remains limited to Level 2 installer training – not just for apprentices, but across all experience levels. The origins of NVQ qualification (Section 4.4.1.1) provide an explanation for why NVQ training appeared to do little to deliver technical knowledge.

Adding to the problem, these formal structures of training and certification serve 'first-tier' agents (e.g. installers) but no relevant structures are available to management or other 'second-tier' roles. New programmes for second tier actors should be considered.

Lipman's (2003) argument for reflective educational pedagogy (Section 4.4.2.2) informs the analysis made here. It enables us to understand that SWI installers – who are on the whole not in academic education past the age of 16 in the UK – approach their work and assimilate (or do not) new knowledge formally but also informally. It sheds light on the reactions of NVQ trainees to written test questions and assessment of quantitative abilities presented in Section 8.6.5. It suggests that formal training may need to target a fostering of *understanding* rather than simply attempt to convey technical information and test retention through NVQ certification.

Assessment and certification

Even ignoring the shortcomings of NVQ training, there is reason for concern that the assessment process itself is often not conducted appropriately and may be routinely undermined (Section 8.6.6). The observations of NVQ assessment and certification suggest that the current system cannot ensure security of investment in SWI. The imperative of improving assessments becomes even more pronounced if the possibility of expanding training to other first tier actors or to higher levels of qualification is considered.

To be fully meaningful, qualifications must be rigorously assessed. Candidates should be easily tracked from job to job throughout the assessment process, but – to ensure ongoing quality work – they should also be tracked past the point of qualification. This might entail issuing unique identification numbers to be linked to all installation work, just as occurs in the GasSafe qualification programme.

Observation suggested that assessors may not be remunerated adequately. It is likely that while this may explain some of the shortcomings in assessment practice; a more systemic under-valuing of qualification is also to blame. Until qualification in SWI is viewed as being as worthy (and as difficult to obtain) as qualification in parallel trades (e.g. heating engineering), this situation may not change. This must be resolved both through top-down and bottom-up action.

9.5.2.3 Policy and funding mechanisms

Given that NVQ training is the sole mechanism for formal instruction of first tier actors (and in fact only applies to installers), the reliance in policy programmes on NVQ to ensure that installers and industry members are technically proficient appears deeply flawed.

PAS 2030 certification is an integral part of new government-led programmes (namely Green Deal and ECO) and this has triggered an increase in enrolment in NVQ 2 training and manufacturer carding. Yet observation indicated that while millions of pounds are being spent on retrofitting, policymakers have not adequately addressed the dearth of technical understanding among installers and managers in order to ensure unintended consequences are not propagated.

The siloisation between the bodies that incentivise and administer funding of retrofits and between those responsible for regulating building works and promoting training (see Section 8.7.4) is compounded by an equivalent siloisation of industry and the CITB from academic expertise in SWI risks. This presents a significant and worrying lack of joined-up policy and strategy.

Perhaps even more troubling was opinion registered from several participants that training colleges as well as assessors often have a "money first, quality not" outlook. Despite the high risk and impact of unintended consequences, government policy is triggering hundreds of millions of pounds in investment, while failing to ensure that the industry is capable of delivering functional and safe retrofits.

The industry, however, is also culpable. The industry levy system which funds training (Section 4.4.1) presents a 'closed loop' conundrum: if industry is solely responsible for setting priorities for training and recognising when current programmes are inadequate, and it is not aware of its own shortcomings or the inadequacies of existing programmes, then it is poorly placed to recognise the need for reform. Until shortcomings in SWI practice become widely recognised, it is unlikely that training will be improved. By then, many thousands of retrofits will likely have been completed by practitioners trained under current NVQ curricula (or without NVQ training at all).

Models found in other European countries, such as the BSEI in Luxembourg (Section 8.6.5.5; Figure 75, overleaf), demonstrate that industry-funded training can provide robust and effective training in retrofit.

Figure 75: Photograph showing construction training programme at Luxembourg

It appears that without further intervention, the inadequacies in training are unlikely to improve. This has bleak implications not just for improvements in SWI practices. It also suggests that the Select Committee's (House of Lords Select Committee on Economic Affairs 2007; Section 4.4.1.2) warning of further potential for low wages, limited economic growth and disaffection for those entering the profession may be realised. To avoid this, collaboration is required between industry, training and academic figures. Undoubtedly, this can be supported by leadership from government.

9.5.2.4 Unstructured knowledge exchange

The 'economic' and 'managerial' 'schools of thought' described by Tennant and Fernie (2013) (wherein learning occurs through accidental discovery and accrued understanding) (Section 4.4.3.2) seems to describe a significant proportion of learning in the SWI industry. Conversely – like Tenant and Fernie -- this research found a relative disregard for more highly-structured learning (e.g. apprenticeship or accreditation programmes) (i.e. *developmental school*) or the even more refined knowledge management and dissemination mechanisms (e.g. organisation and project intranets) encapsulated in the *process school*.

Lave and Wenger (1991, p.93; Section 4.4.2.1) distinguish between 'learning' and 'teaching' curricula and point to "situated opportunities…for the improvisational development of new practice" in learning curricula (Section 4.4.2.4). Opportunities for this in current SWI practice, as observed here, are limited by the disperse nature of projects and siloed work of crews. Site and contract manager 'walk-arounds' (Section 8.5.2) were one mechanism by with 'learning curricula' could be seen to reach installers. However, the limitations in understanding and expertise of these figures described in Section 8.5.1 suggest that to optimise their potential, ensuring that they become adequately trained is important. This underscores the argument for implementing new training programmes for non-installers (equivalent to NVQ 3 or NVQ 4) and to reimagine NVQ training to include more technical content in lieu of its current 'workplace focus' (Section 8.6.5.3). A different opportunity would be harnessing 'thought leaders' among installers and employing a structured 'cross-pollination' of practices (i.e. rotation of crews) on sites. A range of other opportunities might be imagined.

Lave and Wenger highlight the potential limitations of reliance on 'teaching curricula' (1991, p.93):

> When a teaching curriculum supplies – and thereby limits – structuring resources for learning, the meaning of what is learned (and control of access to it, both in its peripheral forms and its subsequently more complex and intensified, though possibly more fragmented, forms) is mediated through an instructor's participation, by an external view of what knowing is about.

This was closely reflected in the observations of this research in which the limitations of expertise of instructors and shortcomings of the NVQ curriculum, as well as engagement with training by learners, were notable.

Legitimate peripheral participation (LPP) (Lave & Wenger 1991, p.40; Section 4.4.2.1) is an important form of 'learning' in the context of SWI. Against NVQ and carding training (examples of active "glass box" learning experiences), knowledge is perhaps more significantly simply 'absorbed' through LPP. The success of this exchange is contingent on aptitude, and crucially, on exposure to settings in which appropriate knowledge and models of behaviour exist. Lave and Wenger argue that these settings are complex sociocultural milieux. The 'accidental' settings in the SWI landscape which shape LPP at present might be made more conducive to knowledge exchange with considered and structured intervention. The harnessing of appropriately trained thought leaders as pointed to in this section could disseminate sound understandings and 'good practices' across sites which at present are highly disperse. (Lave & Wenger 1991)

The community of inquiry paradigm (Section 4.4.2.4) suggests that installers assimilate knowledge within boundaries. The paradigm suggests that journeymen are co-producers of knowledge alongside uninitiated installers, and co-production extends (or could extend) to managers, manufacturers, external experts, regulators, and the full range of relevant SWI actors. The imperative here is to ensure that connectivity within the SWI community of inquiry is robust enough that researchers, technical experts, and well-trained professionals are very much within its boundaries. This will result not just in 'transfer' of information from expert to installer, but also in the reverse direction. A closer understanding of the perspective of installers will allow buildability issues to be understood and addressed by manufacturers and relevant stakeholders more readily. It will also inform supply chain members, but also regulators, insurers and trainers of conventions of site practice (including short cuts and rules of thumb, but also common deviation from specification and best practices). Thus, mitigation strategies can be developed where appropriate. Improving quality in SWI will rely on robust exchanges across the community.

This is not to suggest that installers need be as expert as material engineers or building physicists. However, there is clear need for installers to possess *some* of their understanding. Equally, scientists and manufacturers must be exposed to the understanding and experience of installers.

9.5.2.5 Atomisation and siloisation

In line with the findings of Bartsch et al. (2013) and Dahl and Pedersen (2004) (Section 4.4.2.3), this research found that the atomised and siloed nature of SWI practices, and lack of structured approaches to foster knowledge exchange compounded other obstacles to successful knowledge exchange. Indeed, few opportunities for 'cross-boundary' or social transfer appeared to exist. This appears typical of the RMI sector (Killip 2011) and engenders a clustering of knowledge which in turn further impedes informal learning.

CoPs (Section 4.4.2.4), as Wenger et al. (2002) explain, offer social fabric essential for learning; they promote contact and thus stimulate exchange of knowledge between members. If the siloed character typical of many parts of the SWI landscape can be overcome (even if purely metaphysically), the sense of community and 'domain' of knowledge necessary for effective CoPs may follow naturally. Overcoming the existing legacy will require meaningful investment in programmes which foster interaction and exchange.

9.5.2.6 Organisational learning

Lapses in technical understanding and general competency observed in this research were understood as rooted in systemic, organisational and node (individual professionals) factors. The mechanisms by which knowledge was managed and exchanged by organisations were found to be, on the whole, unsystematic and underdeveloped.

Severe limitations in organisational learning were commonly observed and appeared to stymie the capture and communication of knowledge from projects. This is in line with the reviews of learning in construction given by Tennant and Fernie (2013), Dainty and Edwards (2003), and more notably, Latham (1994) (Section 4.4.2.3). These authors all argue for broader and more consistent use of formal mechanisms to promote organisational learning in construction (e.g. post-project reviews or organisational intranets). The existing paradigm of knowledge management observed in this project suggests an urgent need to reimagine how organisational learning might be better facilitated in SWI industry.

9.5.2.7 Opportunities for improvement

Improving 'quality' hinges on the development of consistent technical understanding and skill across the industry. This calls for effective knowledge exchange and knowledge transfer mechanisms which will in turn require support and insight from models of successful practice.

It is clear that without improving structured approaches to training, current knowledge pathways are likely to result in on-site decision-making which endangers unintended consequences in SWI. In the course of learning, production of understanding should occur in parallel with development of manual skill. Industry must recognise that installers need to understand the implications of good and poor practices, and that they have the capacity to do so.

Rethinking the certifications themselves appears important. This might entail more closely informing – or in fact marrying – technical energy standards, National Occupational Standards, competent person schemes, building regulations and vocational training.

Formal training mechanisms appear, *prima facie*, to offer pervasive transfer of knowledge in industry. The reality, as suggested here, is that formal training is relatively ineffective and needs to reimagined alongside effective strategies to bolster informal knowledge exchange

9.5.3 Aptitude and motivation

Skill and ability to perform tasks – whether manual or administrative – have clear links to training and professional background and experience. Significant variation in this was readily apparent in many observations. Probing revealed not just correlated divergences in training or experience, it also suggested that skill, ability, expertise and understanding often appeared in parallel with factors of motivation, pride and identity. The confluence of these often appeared indissoluble.

It is useful, however, to make two distinctions. 'Aptitude' encompasses the 'ability to do' and the 'understanding to do'; it is 'know-how' and 'know-why'. So aptitude encompasses skill and ability, expertise and understanding, and the capacity to apply these in a productive manner. 'Motivation' reflects personal and professional pride (which in turn hinge on sense of identity) and perceived benefit of action.

Aptitude and motivation were obvious factors in observation of SWI installers and all other roles observed in the research. Obviously, this project did not attempt to assess them empirically. This might, however, be a constructive endeavour for future projects which would provide a baseline to efforts to improve practice in SWI. The themes of aptitude – and to a lesser extent motivation --- which emerged in this research suggest that there is likely to be significant divergence across industry and that these are critical factors of SWI quality.

Aptitude, as a product of formal training, informal learning and knowledge exchange, was discussed in Section 8.6.

9.5.3.1 Pride

Professional pride reflects dedication to excellence; this is examined as "obsessional energy" by Richard Sennett (2009) (Section 4.2.6). It also reflects professional identity, which is discussed in Section 9.5.3.5. In contrast to Sennett's obsessional energy in the manufacturer and sushi chef, little evidence was found of a culture in SWI which internalised excellence as a professional value.

Examination of personal pride revealed factors of self-identity which had fundamental relevance to their work-world identities, behaviours, and – often – capacities. Readings of workplace studies, social history and social theory remind us that certain benefits are the privilege of extended education and economic affluence. This might read as an assertion that the performance of individuals generally correlates with socio-economic status. Yet, very often in these observations, evidence that contradicts this was recorded. The reality observed in this research is that although limited knowledge and understanding often appeared correlated with failure at formal education, marginalisation or disenfranchisement from other areas of work (the result of limited education) often seemed to underlie success in SWI profession. Individuals might have vocalised indications that they worked in SWI because 'options were limited' (Section 8.6.7), but 'success' at SWI offered positive benefit. Personal pride appeared to shape the choice of profession, but equally, professional success affected personal pride. Gaining workplace status or financial reward provided clear opportunity for overcoming perceived limitations in individuals' backgrounds.

This work has highlighted (and attempted to disentangle) some of the complex factors that underlie what on first approach is simple variation in aptitude. A more thorough study of these issues might examine more closely the implications of the polyvalent forces described in this research. Retrofit programmes, government policy, training, and organisational and industry structure and management practice all have intense connection both to aptitude and motivation. As standards across these realms are raised, a parallel growth in empowerment of individuals is likely to ensue. These factors are interdependent; the objective of improving the health of SWI COPs calls for strategic investment of energy and resources across the SWI landscape. In turn, more robust COPs will improve productivity and attainment of excellence in SWI delivery.

9.5.3.2 Intransigence

The fostering of technical, scientific and practical expertise relevant to SWI risks varied considerably in observation among first and second-tier installation workers. This appeared to underlie practices in the delivery of retrofits.

Many instances of gaps in fundamental knowledge were recorded, even among individuals who were placed at important knowledge-exchange nodes (e.g. NVQ training and certification staff). At the 'coalface', ingrained tacit knowledge often seemed to present a barrier to the (relatively minimal) efforts by manufacturers, vocational trainers, of assessors to shape practices. Installers had a strong tendency to 'do as they always had done' and to reflect long-unchanged -- but incomplete -- understandings of principles of SWI performance and risk. This is perhaps partly explained by the heuristic and informal nature of learning which is dominant in the SWI industry; it also likely reflects personal and socio-cultural (or technoscience) constraints on behaviour modification.

In rare instances, dismissal of recommended practice seemed appropriate. For instance: when practical expertise of installers justifiably supplanted impractical specifications (e.g. using a smaller drill bit in unstable substrate, [Section 8.4.1]). These 'rational deviations' from specification were essentially limited to overcoming buildability problems. More problematic deviations were persistent. For instance, while many specific problems in detailing could be overcome satisfactorily in more than one way, a surprising degree of nonconformity with best practice guidance which offered no discernible benefit appeared in observation. Often clearly problematic practices simply appeared engrained (Section 7.4). This suggested poor integration of best practice guidance and scientific understanding with industry norms. In part, this must be attributed to immature knowledge management – at both inter and intra-organisational levels.

Overcoming this barrier will require improving training and knowledge exchange mechanisms, addressing financial factors, and the perhaps knottier challenges of changing identity and motivation discussed in this section.

9.5.3.3 Understanding and aptitude

Expertise and knowledge can be disambiguated as retained information and understanding; possessing raw information does not neatly correspond to expertise. Understanding implies thorough comprehension, nuanced conception, and mastery of information. Understanding enables a *capacity to apply* knowledge. A study of any construction setting will reveal countless instances of instruction. In observation of SWI these included *instruction to* follow health and safety specifics, or *instruction to* follow a particular sequence of assembly. In many instances, it is sufficient that installers *know to* complete a task in accordance with given instructions. In other aspects, a competent installer must *know why* a task requires specific steps in order that she may be able to act autonomously or make decisions independently. In light of the highly-fractured nature of the SWI industry, in which micro-enterprises work in siloed settings and interact with loosely-coupled supporting organisations or administrators, knowledge rather than retained information – the *know why* – is even more important than in more structured and integrated areas of construction work. Coupled with the variety of factors which contribute to engaged and successful professional practice, *knowledge* can be seen as fundamental to the aggregate-concept termed here as *the capacity to apply* expertise. This provides important context for construction management, training of installers and of managers, structures of knowledge exchange and knowledge management. Considering the siloed nature of the industry and the importance of autonomous decision-making and abilities to *know why*, this research has argued for the need for a higher tier professional certification (i.e. above NVQ 2), which would assess managers as well as installers as independent contractors. The present situation, in which only a NVQ 2 certification exists, with its heavy emphasis placed on 'site proficiency' (*knowing to*), appears to be inadequate for the conditions of the industry.

9.5.3.4 Motivation

'Motivation' describes the inclination of professionals to pursue in their work recognizable excellence. It connotes a resolve (however mindful) to apply to one's work consistent dedication and effort above potentially conflicting impulses (e.g. apathy, acquisitiveness, and disinterest).

The theme of motivation which arose during data collection and analysis was simultaneously rich and challenging. It is a nebulous concept and was – at best – sporadically evidenced in the field; to this end, its discussion here has been constrained by inherent subjectivity in evaluation. Despite this, as an issue it is vitally important.

The consequence of 'strong' or 'poor' motivation has clear relevance to quality. As described in Section 8.6, this theme arose in observation of a wide range of professionals; in parallel, in each work-setting a considerable range of potential implications of poor motivation were evident.

Sections 4.2.6 and 4.2.7 introduced the shift from traditional notions of craft, making, craftsperson and maker to modern industrialised production and 'assembler'. Observations certainly showed this shift as relevant to SWI. It appeared in coding under many of the themes of cost or financial motivation, as well as motivation, identity, pride and other topics discussed in this section.

If installers are enabled to become full professionals with all of the identity and domain that implies (through mechanisms discussed elsewhere in this chapter), their pride, motivation and hence engagement with work is likely to improve. Without professionalisation, and without being invested with expertise, aptitude (and so domain), there is a risk of devaluing installers; their product will inevitably suffer.

This research highlighted a range of potential explanations for variance in motivation, in a range of different settings and professional capacities. These often related to financial motivation, perceived disenfranchisement, pride and the sense of professional identity, as well as ignorance of the implications of poor practice (or the importance of following best practice guidance). An example of insight into how motivation might be influenced and might shape workmanship in the context of installation was gained through participant observation as an installer; this is shown in graphically in Figure 76 (overleaf).

Figure 76: Relationships between motivation and workmanship

Future work might explore these topics with more deliberate focus. For instance, the direct and indirect impacts on professionals' motivation of particular attributes of funding programmes borne from government policy seems highly worthy of further attention. Similarly, it would be beneficial to review further any models of positive impact on motivation found in parallel industries or in other countries in order to develop strategies for improving professional pride and quality of output in the SWI industry.

Implications for management

Moreover, this tension may enforce antagonistic relationships. Thiel (2013, p.62) points to a history of literature which delineates a "capitalist dynamic… increasingly controls and degrades work tasks". He argues that relationships between workers and management often display defiance, noting, "Work groups tend to resist formal commands, and control itself can manufacture resistance, especially if it is perceived as arbitrary". By empowering and valuing installers (and all actors), systems of production are likely to be more functional and more sustainable.

Observation of interactions between management and installation staff often displayed tension which appeared rooted in negotiations of role and social power. Contract Manager 1 and Quality Assurance Officer retained tacit and explicit power over installers in all observations in P3 Company; the most obvious explanation for this was their role as 'site regulators' which were justified by their professional positions, but also their perceived knowledge, skill, experience, proxy for the company owner's authority, and outwardly displayed confidence. Their positions of power afforded them the 'privilege' of challenging the standards of installers' work, or to tacitly accept poor practice by overlooking it. Although both figures were generally committed to reasonably acceptable build-quality (which may or may not have been influenced by the presence of the researcher), their enforcement of standards was by no means uniform. Tension between them and installers was not uncommon, and often appeared to be a response to their power as legitimators of practice. Installers, in return, seemed often to resent the assessment of their professional competency. Rather than accepting this as legitimate, the 'cat and mouse' mentality and other indications of defiance were frequently observed (Sections 8.5.2 and 8.5.3).

9.5.3.5 Identity, professionalisation and the 'EWIer'

Mead's analysis of 'me' and 'I' (Section6.8.3.3) provided a lens through which to examine identity and professionalisation among participants. The concept of 'me' contextualises observations with reference to accumulated and socialised understandings. It shows individuals' actions as inherently bound up in this broader fabric. Simultaneously, 'I' highlights the equally important individual response; this helps to understand actions and impulses, self-reflectivity and internal dialogue. Subjectivity and the difficulty of accessing largely internal realities (Section 5.2) have been recognised as significant limitations here. Nevertheless, a sense remains that from a complexity of individual internal responses and outwardly defined character and relationships, the issues of professional identity are real and important.

Furthermore, there is little objective evidence of a strong or long-lasting shared ethos or identity. Formal professional groups have low membership, particularly among subcontractors, barriers to entry in the profession are low, informal networks appear limited and weak, training and assessment exert little bonding influence and -- perhaps most importantly -- security of employment and domain are not such that a convincing history of individuals making a transition from outsider to insider is visible.

These missing indicators of ethos and identity point toward many potential remedial actions which might help to overcome deficiencies. The need to overhaul formal training and knowledge networks which has been discussed in Section 8.6 points to an obvious opportunity of introducing aims of professionalisation and common ethos into vocational training and formal knowledge exchange mechanisms.

Rare references to 'EWIer' as a professional identity were recorded (Section 8.6.7) (interestingly, 'IWIer' or 'SWIer' were not). This suggested that the roots of identity have already formed. Clearly, the history of SWI in the UK is reasonably long -- at least to the extent that probably several hundred professionals have a career in installation which spans multiple decades. Strategies to forge links between them, and establish stronger professional networks linking all first and second tier actors (and others, including trainers, senior managers, or manufacturers) can contribute to a strong 'SWIer' identity. This offers a normalising force to encourage consistent high quality practices.

These findings point to limited shared professional identity, ethos and sense of professionalisation. Hartenberger et al. (2013) identify a lack of professional identity and structure in other retrofitting industries. They argue that medicine offers a model of unification toward a common ethos (i.e. Hippocratic Oath) and a strong, shared professional identity (Section4.4.2.3).

Adapting this model to SWI, we might envision a greater emphasis on training and extension of NVQ2 to Levels 3 and 4 in order to instil both expertise but also pride and professional identity. Training might also contribute to subspecialisation within the industry, which would further bolster professional identity. This would need to be in parallel with much more rigorous qualification assessment. Not only would this provide a better mechanism for ensuring actors are competent, but as systems of professions theory ((Abbott 1988); Section 4.5) tells us, such mechanisms control entry to professions and hence strengthen professional identity. Like in medicine, SWI should create clear lines of personal accountability and should link authorisation to ‘practice’ to strong records of professional practice and reputation. Moreover, as in medicine, a clearly defined ethos should be instilled in all actors in order to bind identity with the ultimate objective which is delivery of high quality retrofits.

Short-termism and workplace culture

Many installers displayed a dispiritedness with their work-world and portrayed it as one in which they are isolated from their employers (installation companies) who, as capital holders, stand to gain (or at least endure) in large project contracts. On the other hand, other sub-contractors appeared to profit from relatively lucrative arrangements and displayed little if any dispiritedness of this sort. Most sub-contractors were loosely coupled to a single principal contractor with limited security in future work. This transience allowed both parties certain advantages but many sub-contractors -- regardless of how satisfied they reported being with pay -- either voiced dissatisfaction with work security or displayed ‘gold rush’ attitudes (Section 8.7.1) toward claiming available work.

Professional pride was observed to vary widely, though in general, it appeared to be limited. Installation crews worked frenetically in response to ‘pricework’ (pay based on insulated wall area). This parallels principal contractors who are paid on a ‘carbon tonne saved’ basis. Largely, pride was observed in relation to ability to produce ‘coverage’ (i.e. earn money quickly), but seldom in relation to tacit knowledge, skill, or technical expertise. In contrast to Sennett’s (2009) observation of “obsessional energy” in the manufacturer and sushi chef, little evidence was found of a culture that internalised quality as a personal or sociologic value.

Moreover, this research has highlighted recurrent mistrust of the insurance and guarantee system by first tier actors, a culture of transferred responsibility, and disaffection (Section 8.6.7.2). This suggests an atmosphere which stymies professionalisation and, hence, improvement in practice and maturation in industry.

Implications of boom and bust

Observation took place at a time of boom in industry, and a sense of excitement about the prospect of continued growth in SWI was pervasive across sites. There seemed good reason to be happy to be in the SWI industry. Almost no reporting of reticence to commit to training, certification or monetary investment was recorded.

It appears that the situation in industry has changed since observation. Collapses in Green Deal and ECO saw expectations dashed[65]. With little prospect of meaningful renewed commitment from government, the industry has gone – if not from boom to bust – from boom to unexciting and insecure.

This is reflected in major cutbacks and job reduction across industry. Carillion, for instance, recently cut £43million and 1,000 jobs from its energy services division reportedly in response to reduced demand (Warren 2014). The Association for the Conservation of Energy (2015) recently estimated that collapse in ECO at the end of 2014 would lead to 10,000 lost jobs and 7,500 new jobs foregone.

Projections of employment in SWI made before CESP and ECO began (Figure 77, overleaf) underestimated job growth but did not forecast recent swings. The implications of faltering commitment from the government for professional identity, sense of short-termism and willingness to invest time and resources are discouraging. For continued, progressive improvement on these fronts to occur, it is clear that cycles of boom and bust cannot persist.

[65] ConstructionSkills Senior Officer (P1), reported that £200 million had been spent to "incentivise uptake" of Green Deal (£125 million in cashback; £40 million in local initiatives, and £2 million in promotion) and pointed to expected £10 billion of private investment during the programme, with roughly 2.5 million SWI retrofits completed by 2022. This was forecast to have provided 60,000 jobs in insulation by 2015.

Due to copyright restrictions, content has been removed by the author of this thesis following examination.

Figure 77: Projections of the variation in employment in domestic insulation sector by type of insulation (Energy Efficiency Partnership for Homes 2008, as cited by (Killip 2011, p.94)

9.5.4 Policy impacts: artificial pressures and false security

9.5.4.1 Impacts of policy

Although numerous drivers and benefits of SWI exist, the primary business model of nearly all SWI principal contractors today appears to be securing and delivering contracts under government-led energy and emissions reduction programmes. Most of these programmes initiate transactions between contractors and the major energy companies. In return for delivering a notional reduction in emissions through SWI, contractors are rewarded a negotiated price. Through the same programmes, but to a much lesser extent, the SWI industry responds to owner-initiated improvement projects -- most commonly, stock improvement projects initiated by social housing organisations.

What emerges is a 'low hanging fruit' scenario. Contractors -- either directly or through brokers -- negotiate with energy companies the 'delivery' of energy and emission reductions. Energy companies reduce the cost of these reductions under essentially free market conditions as they seek best 'value' among many options. SWI contractors, meanwhile, bid to deliver notional emissions reductions, and seek to maximise profit in proposed retrofit programmes. Economic forces dictate that the easiest and therefore lowest most profitable reductions will be made from area-based projects in homogenous building stocks.

What results is the ‘gold rush’ phenomenon that has been described (Section 8.7.1), in which contractors rush to develop the most profitable potential projects to ‘sell’ to the energy companies. Observable on the ground is a scramble to tap funding while it is available and deliver as many retrofits as possible at the lowest possible cost.

This has largely defined the SWI industry. Prior research has outlined a similar phenomenon in parallel areas of RMI. One review in 2008 noted, “The existing industry established around installation of grant-supported measures (cavity wall insulation, loft insulation, etc.) views government policy as a key determining factor in fitting insulation as a stand-alone activity, for which this industry has grown to become effectively a group of specialists” (Energy Efficiency Partnership for Homes, 2008; as cited by Killip 2011, p.92).

9.5.4.2 Direct influence on quality

Policy instruments set *de facto* quality aspirations by establishing norms such as required guarantee periods or prescribed QA procedures. Rather than serving as minimum acceptable standards, these become normative influences. For instance, the required 25-year guarantee under ECO (expanding the 10-year period in CESP) has triggered a concentrated effort to improve build-quality. Despite this, the requirement limits incentive for installers to build to higher standards; aspiring to service lives in excess of 25 years becomes unprofitable. In simplistic terms, this appears as diminishing profit for increasing service life.

An ideal alternative might be a form of energy performance contracting. This would set compensation to installation companies (or cost to funders) against energy savings over time; hence, available profit would increase with investment in longer service lives. This, however, would likely not be a reliable measure given high propensity for energy takeback in improvement projects (Tweed 2013). An alternative scenario would be to set compensation against service life. This could be measured by periodic inspection and absence of call-backs or registered faults. Further incentive could be provided through bonuses awarded for performance of maintenance or end-of-life recovery.

Instead, current programmes pay installation companies in full at the start of service life. Coupled with short programme durations, this appears to reinforce inadvertently a culture of 'short-termism' (Section 8.6.7) and incentivise high output rather than quality.

Another aspect of short-term focus in policy is current stimuli for single-measure retrofit. Evidence is clear that much more than SWI will be needed to meet energy targets. Moreover, as has been described in Section 9.4.1, there are clear advantages to integrated retrofits. Discordance exists between policy which triggers single-measure SWI and the benefits of multi-measure projects. The current system of piecemeal retrofitting might be understood as 'over time' projects (Fawcett & Mayne 2012); in light of energy targets, SWI projects are really only 'partial retrofits' (which cannot in isolation deliver reductions in building energy demand necessary to meet targets). The implications of this for occupant disruption, time and resource inefficiency and added cost are considerable. The pressure to deliver single-measure retrofits is disruptive to natural forces.

Failure to measure occupant satisfaction accurately

In a normal free market, sellers are incentivised to satisfy buyers by the prospect of return business or strengthening of reputation.

Policy programmes supplant this mechanism; installers have little real incentive to satisfy occupants.

Occupant and owner satisfaction is currently measured under policy programmes (almost universally) by a short survey at retrofit completion. Many of the problems caused by poor installation or specification, however, are likely to take months or years to become noticeable. Therefore, this measurement of occupant satisfaction is almost certainly not fully meaningful.

The satisfaction of occupants and owners appears to be toward the bottom of priorities of the observed installation companies. Where notable importance is apparent, it seems related to ensuring reasonable (i.e. not excellent) ratings in post-completion surveys. Asset managers, meanwhile, were explained by several actors as generally hesitant to complain in light of the significant investment in their stock their organisations were receiving at no, or little, cost.

Accountability for build-quality appears at key points. For instance, occupant and owner satisfaction surveys, guarantor and insurance audits, and gas and electrical safety certificates (often self-certified). A more intelligent approach would measure long-term performance and satisfaction and hold installers and related actors accountable for results.

Time constraint and financial pressure

Policy programmes have a history of operating in short phases (often 6-18 months) and imposing tight deadlines on projects. Underlying this is often availability of funding, alignment of political support, or shifts in policy.

One major impact on the ground is enforcement of the gold rush phenomenon. Installation companies seek to bring as many projects as possible to practical completion within programme timeframes. Because of this, and because their contracts are almost exclusively based on price per notional unit of energy or emissions reduction, a tremendous incentive exists to prioritise 'quantity over quality'.

Trickling down from this, subcontractors – who are paid 'pricework' (pay based on insulated area) -- work at frenetic paces to maximise their own earnings (knowing that periods of boom are not constant) and in response to pressure from principal contractors.

These pressures are intensified by the unpredictability of weather. The implications of this were widely discussed by installers and managers alike.

Meanwhile, the 'low hanging fruit' scenario (Section 9.5.4 is exacerbated by partial funding schemes. ECO, for instance, offers 40-100 per cent funding for projects. P3 Company demonstrated reluctance to pursue part-funded projects, reportedly because they correlated to increased demand from clients for accountability.

Other observations of time constraint and financial pressure were located in training and assessment settings (Sections 8.7.1 and 8.6.5). Training providers, trainers, and assessors all appeared to face parallel 'quantity over quality' pressures. Training providers' pay is based on throughput without any component related to assessed learning or 'output'. This provides a context for the characterisation of some providers as "factories" (Section 8.6.6). Trainers paid on day-rates face much less of this pressure, but again without their incentive tied to 'output', it appears that concern for quality is incentivised primarily by a sense of conscience. This may not be enough to ensure top-quality training. Some indication of an inclination to underpay trainers was also recorded (Section 8.6.5). Worryingly, NVQ assessment appeared affected by quantity:quality pressures (Section 8.6.6). Without adequate remuneration, and in the context of apparent widespread undervaluing of the NVQ qualification and importance of knowledge and understanding, it seems unrealistic to expect assessors will not circumvent protocol.

A very similar pressure appeared to affect surveyors and auditors employed by guarantee and insurance bodies (Section 8.7.5). Observation indicated that inspections are routinely wholly insubstantial. If this is as endemic as suggested by observations, a crucial element of quality assurance is missing.

9.5.4.3 False security

Collectively, funders, manufacturers, installation companies, installers, regulators policymakers rely on a system of financial insurance against poor delivered quality.

This system has been described (Section 8.7.5) as prone to failure due to seemingly inadequate inspection and control of installation processes, and to probable widespread shortcomings in appropriate installation and specification.

False security exerts a form of artificial pressure; if the consequences of actions are unrecognised or their cost rescheduled to future repayment, perceived cost (I.e. net present value) is significantly reduced. Hence, poor assumptions about consequences normalise practices which are inherently problematic.

In a chain of transferences, liability for poor practices is conveyed away from funder and manufacturer, past surveyor and certifier, and toward primary contractor, subcontractor, insurance and guarantee agency and underwriter.

Policymakers are blindly accepting (or denying otherwise) that the current system is unlikely to be capable of providing adequate insurance. The impact of large-scale failure is high, and the potential costs of may be measured in billions of pounds. The risk of this occurring must be minimised.

Table 7 shows a range of potential scenarios based on notional cost assumptions, presented to support this argument. This shows hypothetical costs associated with partial or full replacement of SWI, remedial work to the building, or legal claims by occupants (for injury, health impact, or other liabilities). Assumed values include:

- £4,000 (partial system replacement or modest remedial work);
- £10,000 (system replacement or substantial remedial work);
- £25,000 (system replacement and/or remedial work and/or occupant legal claim);
- £100,000 (extensive remedial work and/or occupant legal claim); and
- £175,000 (condemned structure or significant legal claim).

These costs are multiplied by rates of 5, 10, 20 and 30 per cent of approximate existing installations (250,000) or potential future installations (500,000). Again, these figures are for the purpose of demonstration only and were not discussed with participants . Nevertheless, recent evidence cited in Section 9.4.2 indicated that nearly 20 per cent of sampled ECO-funded SWI installations had substantial failures; there is ample reason to suspect this may have been underestimated. Future research might monetise potential scenarios of SWI failure in a deeper analysis.

Table 7: Hypothetical cost of SWI replacement, remedial work or legal claims against various scenarios

Cost per failure (£)	Cost to insurers (£, million) per retrofit failure rate, 250,000 houses				Cost to insurers (£, million) per retrofit failure rate, 500,000 houses			
	5%	10%	20%	30%	5%	10%	20%	30%
4,000	50	100	200	300	100	200	400	600
10,000	125	250	500	750	250	500	1000	1500
25,000	312	625	1250	1875	625	1250	2500	3750
100,000	1250	2500	5000	7500	2500	5000	10000	15000
175,000	2187	4375	8750	13125	4375	8750	17500	26250

Even the lower rates of failure here would not only derail government efforts to meet energy targets but would have serious consequences for consumer confidence in retrofit and would have bleak implications for loss of personal and cultural value in the built environment. If, as many participants suspected, in future failures insurers and guarantors were to hold installation contractors accountable wherever possible, it is clear that collapse of many companies would follow even moderate rates of reimbursement or compensation claims. Observation recorded numerous statements of mistrust of the current insurance and guarantee system (Section 8.6.7). The present system appears to risk enforcing a culture of mistrust and resentment among installers.

Observation recorded numerous statements of mistrust of the current insurance and guarantee system (Section 8.6.7). If, as many participants suspected, in future failures insurers and guarantors were to hold installation contractors accountable wherever possible, it is clear that collapse of many companies would follow even moderate rates of reimbursement or compensation claims. Aside from financial instability, the present system appears to risk enforcing a culture of mistrust and resentment among installers.

Some distinct points of accountability for practices already exist – for instance at handover, gas and electrical sign-offs, funding audits, and contract completions. More meaningful inspection, auditing, and points of accountability throughout the process would help to ensure that faith in the current system might be justified.

9.5.4.4 Implications

Top-down mechanisms of incentivising retrofitting have clearly stimulated remarkable growth in SWI installation. Their transitory and disjoined nature, however, has inadvertently exacerbated difficulties in achieving consistently high levels of quality.

Many factors have been described in this chapter as underlying the quality gap in SWI. These are compounded by the artificial pressures and false securities exerted by policy. This might be conceptualised as shown in Figure 78 and Figure 79 :

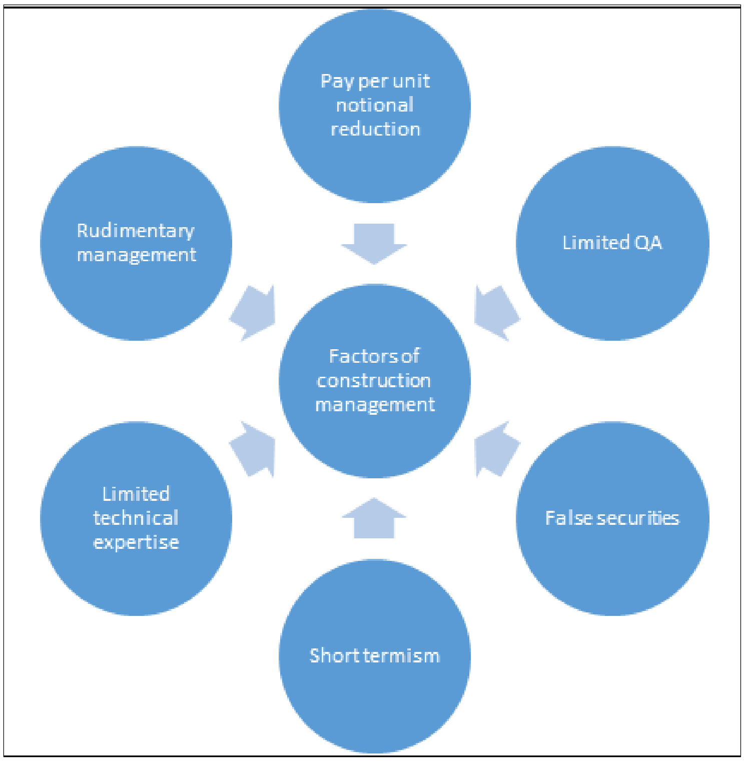


Figure 78: Factors of construction management

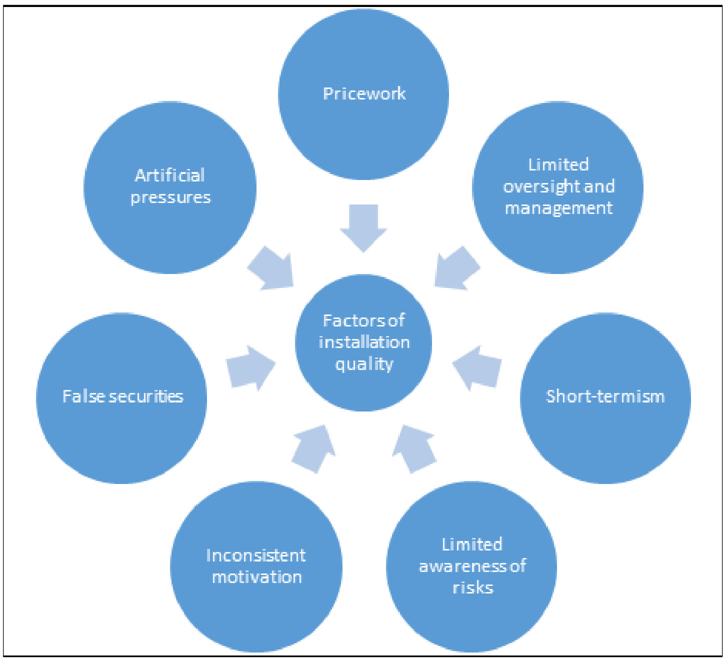


Figure 79: Factors of installation quality

This research suggests that the policy instrumentation should be carefully examined for adverse impacts on the readiness with which installers and first tier actors are able to deliver quality in SWI. A question remains as to how the perspective of installers will be heard by policymakers, as considerable distance exists between the two groups. The description of upstream influence from middle actors to policymakers given by Janda and Parag (2013) (Section 3.2.2.1), may be an overstated capacity for influence on policy. Particularly in the context of SWI installers, upstream influence is likely to be infinitesimally small. There appear to be very few mechanisms for consultation of these coalface middle actors and their voice and perspective do not seem to be reflected in current policy or debate. The direction of power between policymaker and building professional in SWI is overwhelmingly top-down. Therefore, it must be recognised that considerable responsibility for mitigating artificial pressures and assuring financial sustainability in SWI lies with those at the 'top' of this system.

At the end of his doctoral thesis, Killip (2011, p.289) presents a simple graphic to illustrate his argument that "policy-industry networks are key to the success of policy innovations…" (Figure 80). His argument is equally relevant at the end of this research.

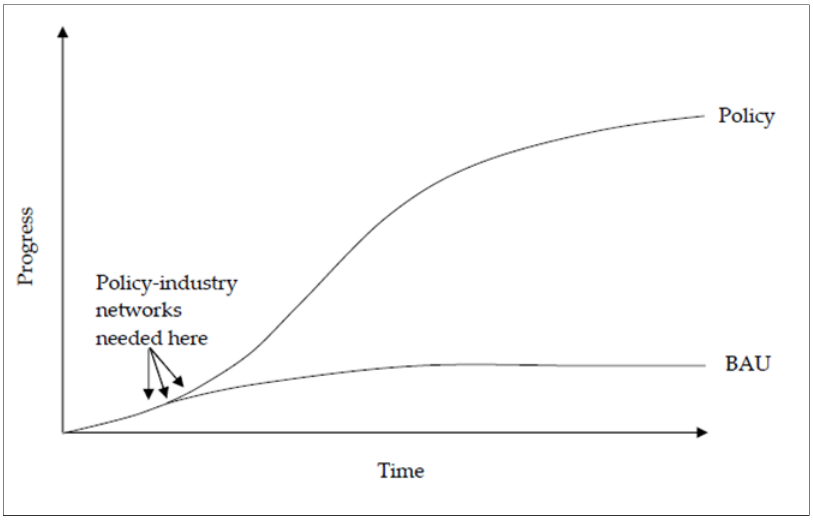


Figure 80: 'The role of policy-industry networks in shifting away from business as usual (BAU)' graphic from thesis by Killip (2011, p.289). (Permission to reproduce original content granted by copyright holder)

Informing each side of the policy-industry partnership with the perspective and knowledge of its counterpart, and focusing on how the two sides can be more closely aligned are hugely important avenues for future work. Additionally, the interrelationship of industry with the many other drivers of SWI retrofitting needs to be investigated more deeply in future research.

These issues may have significant implications for knowledge and skills capital, job security and retention of workers, long-term security of investment, and not least, the quality of retrofits.

In light of contested negotiation of ground between policy bodies, siloisation across government (and industry), and the political processes which lie behind programme development it is concerning that these problems may not be addressed swiftly. Through progressive improvement, future iterations of policy should strive to create stable conditions in industry.

9.5.5 Technology

In its examination of quality, this research has highlighted advantages and encumbrances intrinsic in a range of SWI materials, tools and techniques (described here as 'technology').

There is a relatively narrow range of technology commonly employed in today's industry. This appears to reflect a general conservativism in the trades. Yet apart from the observed conventions, a range of options with significant advantages are readily available but remain underemployed. Both the conventional technologies and those which are available but not employed lack a variety of 'ideal' attributes.

The research has responded to this reality in two ways: it has sought to document advantages and disadvantages of technologies which were encountered, and it has asked why the current trends exist. These are two very different lines of enquiry.

9.5.5.1 Presently employed technology

SWI is applied through manual processes without automation or digital technology. Materials are handled, measured, cut, fixed, fitted, or applied in a traditional manner which shares almost nothing with modern manufacturing or vanguard construction techniques.

As observations have shown, current technology is highly vulnerable to installer practice and inappropriate specification. SWI is installed through a relatively long sequence of individual tasks (e.g. surface preparation, measurement, cutting, drilling, fixing, rendering), almost every one of which presents opportunity for error and requires skill and care to accomplish properly. There is an intrinsic delicateness to the process, against which materials and tools appear unevolved and unwieldy.

A certain amount of skill and craft is inherent to any building work. But the modern paradigm of design and construction commonly attempts to eliminate this wherever possible (Section 4.2.6). Against this, SWI seems a vestige from an earlier age. If SWI reflects the complexity of assembling a delicate soufflé in a home kitchen, many modern approaches to construction are akin to a ready-mix cake or a store-bought pastry.

Someday, the delivery of SWI might reflect the efficiencies of MMC. The present technology and manual task-system calls for significant improvement in order to minimise error and waste while improving productivity.

Assessing technology and 'buildability'

Buildability is relevant not just to the installation phase, but to all ensuing requirements to work with a material. An SWI system must be maintained, particularly in relation to mechanisms of moisture management. A verge trim for instance might be sealed with a 25-year silicone sealant, but common knowledge suggests this must be regularly checked and reapplied throughout its service life. This requires not only roof access, but difficulty in removing degraded sealant and reapplying it. Amending Killip's definition of buildability (which included the following characteristics: 'practical'; 'replicable'; 'affordable'; 'reliable'; sellable'; 'available'; 'guarantee-able'; and 'profitable') (Section 4.2.4), we might add 'maintainability'; this becomes a ninth characteristic of 'buildability': serviceable.

Observation, particularly participant observation revealed consistent shortcomings against this definition of buildability. Observation (Section 7.4) revealed many elements of SWI technology were: difficult to implement ('practical'); prone to installer error (replicable); likely to fail due to poor practice (guarantee-able and sellable); had limited robustness or service life (reliable); or were prohibitively expensive (e.g. tools, materials) (affordable).

Another valuable way of assessing technology is its performance in-use. Most obviously, this includes energy performance of insulation. It also includes robustness – for instance, the enduring adhesion of a silicone seal, or the resistance of trim or undercill to weather exposure (e.g. fading or splitting). Equally important, it also includes environmental impact over the life cycle. Materials or systems with short service lives, high maintenance requirement, or poor end-of-life scenarios can be seen to fail not only against the above definition of buildability but also in performance in use.

For instance, some insulants (e.g. phenolic foam) are particularly difficult to recover or reuse, particularly at end of life.[66] Although some areas of design and construction industries are working toward addressing these issues in a progressive manner, to date little recognition of the issues in SWI can be found (Adams 2012)[67]. The failure of products due to intrinsic weakness, but

[66] Some manufacturers provide site pick-ups for recovery of insulation waste for re-use (typical of mineral wool insulation)

[67] Further action is needed to remove ODS foams from the built environment. Although these are more likely to be found in industrial and commercial buildings than in domestic buildings, their degradation contributes massively to GHG levels and are an important focus for waste and SWI research.

also their vulnerabilities on site are among the shortcomings of current tools and techniques.

9.5.5.2 Human-technology relations

Conservatism in technology may, *prima facie*, defy logic. Investigated more deeply, however, rational explanations offer insight. Selection and deployment of technology can of course be understood in the context of external forces which shape availability and functionality of various tools and materials. More complex shaping forces are also at work, however.

Individuals 'produce' in the SWI landscape and hence quality is plainly a human issue (with all of the social-cultural complexity that this entails). STS demonstrates that behaviour and technology are coevolved (Section 6.8). Just as SWI practices cannot be disentangled from identity, motivation, or the impacts of policy, this mesh of interrelationships also includes technology. STS, and ANT in particular demonstrate that the agency and constraints of technology and actants exert powerful normative and determinative forces (Section 6.8). Material-semiotic analysis allows understanding that between actors, intentions, expectations, signals and other communications are often transmogrified. This may mean that SWI technology as intended or envisaged by one party may appear very differently to another. In the context of SWI, this suggests deep relevance of technology to working practices, perception and identity, and equally important reciprocal influences.

In observation, these lenses reveal complexities beneath for instance, disdain, mistrust, or apprehension of certain materials, techniques. They may offer some explanation of why an installer hand-trowels render or cuts trim with a handsaw. Conservatism becomes more comprehensible when complexities are understood.

The implications are multi-dimensional. This analysis can lead to a conclusion that conservatism in technology is bounded to broader conservative attitudes. It may be that if understanding, pride, and expertise can be influenced, evolutions in technology will duly follow. Another analysis might be that by introducing new technology -- perhaps leveraged through policy – disruptive, but productive shifts in attitudes, identity constructs, behaviour and ultimately practice might ensue.

STS tells us that constructs are complex, and decision-making is not easily understandable. To an extent, efforts to leverage change may in fact be misguided and the impenetrability of relevant black boxes (Section 6.8.3.3) to problematic. It may be unrealistic to assume that intervention can effect real change in product choice, use of tools or techniques. Steeper still is the challenge of driving change in care, attention, pride, or any number of social phenomena seen as obstacles to improved practices. The value of STS may simply be in the richness of understanding it affords of the complexities of technology. Nevertheless, when interlocked constructs are unpicked, it is difficult to resist the notion that intervention cannot (or should not) follow.

In its focus on the indissolubility of technology and culture, and innovation and socio-political factors, there is clear relevance in STS for this research. This research has avoided engaging heavily with social constructionist theory. This is most certainly not an acceptance of countering essentialist viewpoints on technology. This research has not attempted to engage fully with STS, but some insight has been gained from exploring complexities of technology. With this qualification, the analyses achieved offer potential explanations for some of the trends observable in technology and wider SWI practice.

In less abstruse application, examining the relationships between technology and people can deepen understanding of retrofit quality. Nösperger et al. (2011, p.1366) challenge the "synaptic path that leads policymakers to think that technology is separate from people" and argue, "We need to think of people and technology as two sides of the same coin, which develop in a process of coevolution, with technology shaping behaviour and vice versa". Quality is not simply related to people, and neither just to technology; it emerges from the relationships between the two.

Need for innovation and adoption of niche market materials

Evaluated against the multiple dimensions of buildability, it is clear that technologies in the mainstream market have many significant limitations. Observation suggested that innovation and new technologies have potentially important contributions to make to improving levels of SWI quality. Equally, there are many advantages to existing materials which remain in 'niche markets' (Appendix C).

Manufacture of high performance insulants such as VIPs and aerogel is inherently expensive (compared to conventional materials) and innovation in this area is important. The thin profile they afford would have hugely beneficial implications in SWI. At present, they remain niche products. Further benefit could be derived from high permeability materials with low lambda values.

The 'breathability debate' (Section 2.5.2.3) suggests uncertainty about the appropriateness of mainstream SWI materials. This may warrant wider use of 'breathable materials' (Figure 81). Limitations in the supply chain of many existing materials, higher transport distances, and higher lambda values are all significant obstacles. Innovation here is warranted.

Figure 81: Mock-up of wood fibre insulation

Poor buildability repeatedly suggested opportunities for innovation or adoption throughout Phases 2 and 3. The time-intensity of trimming-out, for instance, might be alleviated by modularising products (e.g. base rail, corner trim, and soldier course insulation boards). Long drying times of most renders (about three days) which causes significant 'clogs' in workflows, might be addressed by employing alternatives (e.g. M1 render which dries in less than one day). Higher cost was cited by managers as limiting use, but when potential savings on scaffolding and equipment, and reduced project complexity, a higher cost seems easily justified.

Employment of MMC and digital technology seems long overdue in SWI. It is difficult to rationalise the continued reliance on manual handling and traditional techniques of measurement, cutting, and fixing. Developments in 3-D laser scanning, CNC machining, modular construction, a range of non-destructive test techniques and supply chain management suggest real opportunities here. Innovation would optimise resources, improve accuracy and likely reduce costs. One example of progressive use of technology is an IWI system employed by United House which digitally scans room dimensions to enable computerised cutting of insulation off-site (United House 2013).

Conversely, materials with lower embodied energy or lower intensity of manufacturing offer desirable traits (Figure 82). Although embodied impacts of materials are generally dwarfed by operational savings of energy, these impacts are not insignificant and will become proportionally more important in SWI as operational efficiency across the building stock improves. To meet carbon and sustainability targets, reducing supply chain impacts will become increasingly important in future years.

Figure 82: Cellulose insulation manufacturing facility

Nevertheless, hypothetical discussion must be joined by the realities of the current technology landscape. Observation and research has uncovered a number of significant obstacles. These relate to supply chain readiness and responsiveness; communication and knowledge exchange between industry and manufacturers/suppliers; market inertia; trust; market demand; and lack of incentives in policy programmes. Although there is a clear need for changes, technology transition is notoriously difficult to leverage.

9.5.6 Potential for redefinition of professional roles

9.5.6.1 Systems of professions

In analysis in this thesis, the system of professions theory provides a useful way of understanding 'relevant competencies' and the importance of installers and industry in the 'middle ground' of SWI retrofitting.

If the SWI installation industry cannot deliver safe and effective retrofits, the public may eventually fully reject the professional it recognises as an 'SWIer'. This theory suggests that the SWIer may become prone to self-destruction and incursion.

One route to safeguarding against this would be if installers were to adopt radical new technologies which facilitated a dramatic improvement in practice. This would likely start within a fringe group. New technologies provide impetus for shifts in professional identities and negotiation of "jurisdictional claims".

In SWI, it is likely that this tension – rather than being a divisive force – would result in significant change. Current technology presents not just considerable vulnerability to workmanship and installer practice, but numerous shortcomings in buildability (Sections 8.4 and 9.5.5.1).

The broader body of work which examines the way in which professions function and change over time, has provided context for a growing discourse that interrogates its significance for the refurbishment industry.

9.5.6.2 Middle actors

In the 'middle ground' (Bordass & Leaman 2013), the actual implementation of the retrofit occurs. The practices employed in implementation are hugely important to performance and avoidance of unintended consequences (Figure 83).

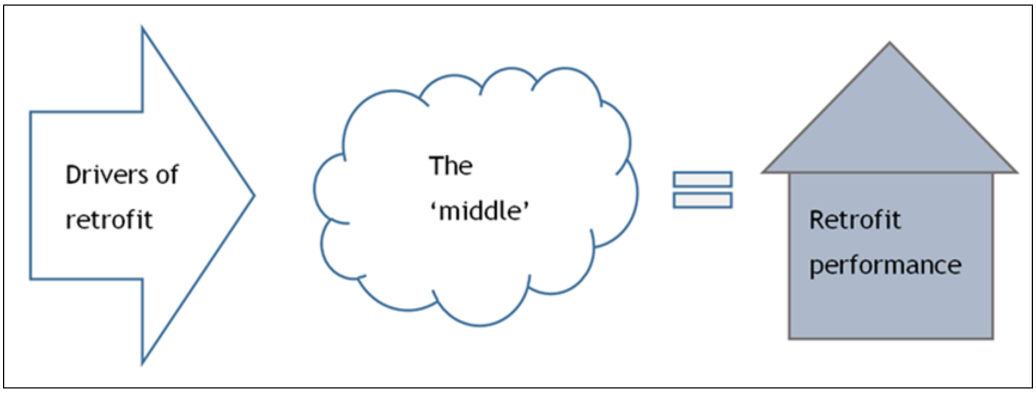


Figure 83: The 'middle' in retrofit performance

Writers increasingly argue that a "middle-out" perspective acknowledges links between actors and highlights significance of actors positioned between government regulation or policy (top-down mechanisms) and individual, organisational, or grassroots agents of change (bottom-up mechanisms).

Janda and Parag (2013) hold that that in between policy and implementation, those in the 'middle' (most building professionals) are often overlooked and not adequately motivated and trained (Section 3.2.2.1). They argue (2013, p.42) that understanding of middle actors in refurbishment work has only begun to be developed, and point to needed emergent ethnographic research and situated work as showing that "intermediary groups… have their own habits, practices, ways of thinking about problems and ways of working that affect their ability to provide (and interest in promoting) low-carbon buildings.". This project answers their call. The following discussion provides conceptualised improvements in response to the understandings that have been produced.

9.5.6.3 Multi-skilling and the need for an 'integrator'

Very little research has attempted to understand the reality 'on the ground' in retrofitting. A growing body of research, however, is recognising that energy refurbishment presents a demand for new skills, new understandings, and new roles, and is beginning to ask questions about how what occurs 'in the middle' can be more closely aligned to the energy agenda.

Significant voices have pointed to a lack (or deficiency) of a skilled workforce able to meet the requirements of retrofitting (European Council for an Energy Efficient Economy 2011).

Many of the authors in the issue of Building Research & Information discussed in Section 3.2.2.2 argue that professionals have not yet adapted to the 'newness' of the sustainability agenda, and lack the knowledge and skills it requires. The issue's papers argue for internal changes which centre on identity, training, a sense of shared mission, and improved knowledge and skill transfer. These arguments resonate deeply with the findings of this project.

Janda and Killip (2013, p.36) note that "literature on innovation in residential refurbishments is comparatively scarce" and call for improved understanding of the need for building expertise. They (2013, p.41) suggest a need to focus on *how* people install technologies. This is a rare argument but one which reflects the purpose of this project. They acknowledge a much more significant literature examining how people *use* technologies. They show that in both contexts, intermediary groups are understood to have habits, practices and modes of thinking and working. They assert significant importance of intermediaries to the performance of refurbishments, and highlight the question of competency in industry.

One solution to the inadequacies of skills and knowledge in retrofitting is the 'multi-skilling' of professionals to enable them to take on roles broader than conventional definitions. Killip (2011, pp.250–251) describes multi-skilling of an actor as the assumed accountability for a collection of related tasks (i.e. a sub-system of a project rather than individual tasks). He uses an example to explain:

> …the heating engineers who fit insulation under floor-boards can thus be re-conceived not simply in terms of merging two practical skills, but as taking responsibility for pipework, thermal bridging and moisture management at the junction between floors and walls.

This would undoubtedly require not just substantial training but also negotiation around existing profession 'groups'. Janda and Killip (2013, p.43) explain, "The traditional focus of training has been on traditionally defined trades." But, they argue, new LZC technologies present a need for traditional trades to engage with the multi-skilling agenda. As described in Section 3.2.2.3, however, Killip (2011, pp. 203; 251) highlights "strong counter-arguments" rooted in "conservatism of the trades" as significant obstacles to this agenda.

The concept of 'multi-skilling' describes precisely a part of the challenge that SWI entails: SWI necessitates new understanding, knowledge, skills and this calls for negotiation of job roles. Yet latent conservatism in trades, and the challenge presented by inertia in training (Section 9.5.2.2) and in knowledge management mechanisms (Section 4.4.2.3) may present formidable obstacles to developing highly capable multi-skilled professionals able to address present deficiencies in the SWI landscape. If it is failing under present conditions, more drastic intervention may be required.

What is clear is that the industry – and no less the research community – has not yet understood how a transition to successful mature practice will occur.

The WBCSD's argument for a system integrator (Section 3.2.2.3) which may offer a promising solution for the knowledge deficit, but also the problems of siloisation and poor knowledge flow described in SWI (and elsewhere in retrofitting by other authors). It argues that, "The building industry must create and prioritize energy-efficiency training broadly…It is also important to develop a 'system integrator' profession to support retrofitting in residential properties" (WBCSD 2009, p.9). It explains that a 'system integrator' could address skill shortages and "be able to assess energy-efficiency requirements and develop a whole-house plan, select appropriate contractors and manage the retrofit process" (WBCSD 2009, p.61).

The vision of the potential 'integrator' role has been interpreted with slight variations. Against Killip's description (2011) of a technically proficient site supervisor, Janda (2011) envisages a profession "based around teaching people how to use buildings in less consumptive ways" and draws an example of similar instructive professional roles from public health occupations.

Janda et al. (2014, pp.931–932) describe a series of interfaces in refurbishment and argue for deeper integration at all points. They describe interfaces:

> …between products and buildings elements; between the traditionally separate roles played by contractors; and between the effects of physical interventions to buildings and the supposed behavioural response of occupants; and between innovations among products, practices and processes. But there is also a higher-level need for better communication and integration between policy, practice and research.

Different authors have envisaged this concept with different emphasis on the roles of communicator, translator, liaison, expert, and administrator. What all have in common is recognition of a void in the current system of retrofitting.

The discussion of a “system integrator” as Janda and Parag argue (2013, p.42), represents a shift toward “*who* [emphasis in original] is going to make the necessary changes and *how* [emphasis in original]”. This will undoubtedly require breaking down boundaries of traditional identities (Hughes & Hughes 2013). Observation in this research suggests that the required investment to effect this change is not only warranted, but might even offer the least resistance of possible interventions.

The integrator concept certainly offers a strategy for improving knowledge exchange. This is much needed; conveyance of knowledge within the SWI landscape appears limited and, coupled with siloed work forces, ‘clustering’ of knowledge seems pandemic. Observed management practices did little to facilitate knowledge exchange through structured approaches which have been shown to be effective in other areas of construction and engineering (Winch 2002; Carrillo 2005; Kamara et al. 2002; Robinson et al. 2005). A system integrator would help to overcome these obstacles.

As a ‘translator’ between parties, a system integrator would connect the producers of scientific understanding with those who deliver and deploy SWI. This is not a one-directional transfer of knowledge; installers have important perspectives and this would be useful to researchers. Moreover, by connecting installers and researchers more soundly with manufacturers and suppliers, the current loose ties between these actors would be supplanted.

As an ‘expert’ with understanding of science and awareness of risks, the system integrator would ensure that critical knowledge did not slip between the cracks between specifier installer, scientist, manager, surveyor, manufacturer, trainer, and the diversity of actors involved in delivering or supporting delivery of retrofits.

As ‘liaison’, ‘’communicator’ and ‘administrator’, the system integrator would ensure that all parties worked in concert and were well-informed throughout the processes of funding and delivering SWI. The integrator would help to secure that investment triggered by government policy was carefully managed. This would address the sketchy controls of management currently required of primary contractors by funding programmes. More robust accountability is desperately needed.

Adding to the visions shared by other authors, the integrator could serve as a 'thought leader'. Equally, the integrator could serve as a 'champion' for progressive change in projects. An integrator in these ways might reflect a degree of Mead's "attitude of the engineer" which describes a shift in identity between 'I' and 'me' and an internalisation of a collective (see Section 6.8.3) (2009, p.276):

> The engineer has the attitudes of all the other individuals in the group, and it is because he has that participation that he is able to direct. When the engineer comes out of the machine shop with the bare blue print, the machine does not yet exist; but he must know what the people are to do, how long it should take them, how to measure the processes involved, and how to eliminate waste. That sort of taking the attitudes of everyone else as fully and completely as possible, entering upon one's own action from the standpoint of such a complete taking of the role of the others, we may perhaps refer to as the "attitude of the engineer." …
>
> Here the full concreteness of the "me" depends upon a man's capacity to take the attitude of everybody else in the process which he directs. Here is gained the concrete content not found in the bare emotional identification of one's self with everyone else in the group.

As a 'responsible manager', the integrator could rectify the fact that at present those who possess understanding fundamental to achieving quality are largely absent from the coalface of installation. Also missing is an individual who carries responsibility for the performance-in-use of SWI retrofit. Insulation systems with high maintenance demand (for instance with silicone critical seals) are particularly vulnerable and the presence of an expert post-completion could ensure that essential maintenance is conducted and could serve as an advisor for end-of-life recovery. Moreover, the integrator as a 'responsible-manager' could call on resources necessary to inspect or rectify any emergent unintended consequences (e.g. ensuring adequate ventilation, addressing moisture ingress, checking for pointing or spalling in IWI). Particularly at early stages of SWI rollout, where it is clear we are 'not getting it right', it is neither prudent nor advantageous to install and forget. The consequences of neglect will be tremendous cost and impact, vastly greater than any operational savings.

An exploration of how this new professional role might fit within the context of SWI must first map the responsibilities of actors in the existing landscape against various aspects of retrofit delivery. This is provided in Table 8 (overleaf). A graphical representation of how the system integrator would be positioned against current roles is shown in Figure 84 (overleaf) and description of the function provided by the integrator to each role is shown in Table 9 (overleaf).

Table 8: Mapping of responsibilities in current SWI landscape

	Assessment of building and site	Specification	Installation	Maintenance	End-of-life
Owner	Requests EWI/IWI or agrees to installation	Some opportunity for input regarding render colour	None	Full responsibility for understanding and delivering all maintenance requirements	Likely to be responsible for decision-making and allocating responsibilities
Funder	Bases acceptance of project on potential GHG reduction and confidence in project success	• Selects installation company or broker • Transfers responsibility to guarantor and installation company	Manages QA information, directly or indirectly engages guarantor	None	None
Funding overseer (e.g. CESP or ECO)	Stipulates allowable typologies	Stipulates allowable technologies	Stipulates QA, certification standards, guaranty requirements	None	None
Installation company	Manages assessment, directly employs or subcontracts processes	Develops specification in concert with funder or funder's agent	• Selection of contractors • Provision of training • Quality assurance	None	None

(Continued)	Assessment of building and site	Specification	Installation	Maintenance	End-of-life
Surveyor(s)	Identifies potential hazards	Identifies potential hazards	Monitors material usage	None	None
Installers	None	Minor: substitution or work-arounds, detailing solutions	Full responsibility	None	None
Warranty provider	Stipulates acceptable conditions based on data from manufacturer and system supplier	Stipulates acceptable conditions based on data from manufacturer and system supplier	Stipulates acceptable conditions based on data from manufacturer and system supplier	None	None
Insurer/ Guarantor	Inspection and verification of suitability	Inspection and verification of suitability	Inspection and verification of suitable work	None	None
Insulation manufacturer	None	Provides technical data	Provides technical data leading to	None	• Provides technical data • May provide take-back scheme
System supplier	Provides guidance, stipulates warranty requirements	Provides guidance, stipulates warranty requirements	Provides guidance, stipulates warranty requirements	Provides guidance, stipulates warranty requirements	None

(Continued)	Assessment of building and site	Specification	Installation	Maintenance	End-of-life
Construction management	• Identifies logistical issues and develops construction plan • May identify unrecognised hazards or installation obstacles	Communicates specification to installers	Monitors all aspects of installation	None	None
Installer trainer	May develop understanding of risks	May develop understanding of best practice	Responsible for developing understanding of best practice	None	None
Installer certifier	May assess understanding of risks	Limited assessment of understanding of best practice	Responsible for assessing knowledge and competency	None	None

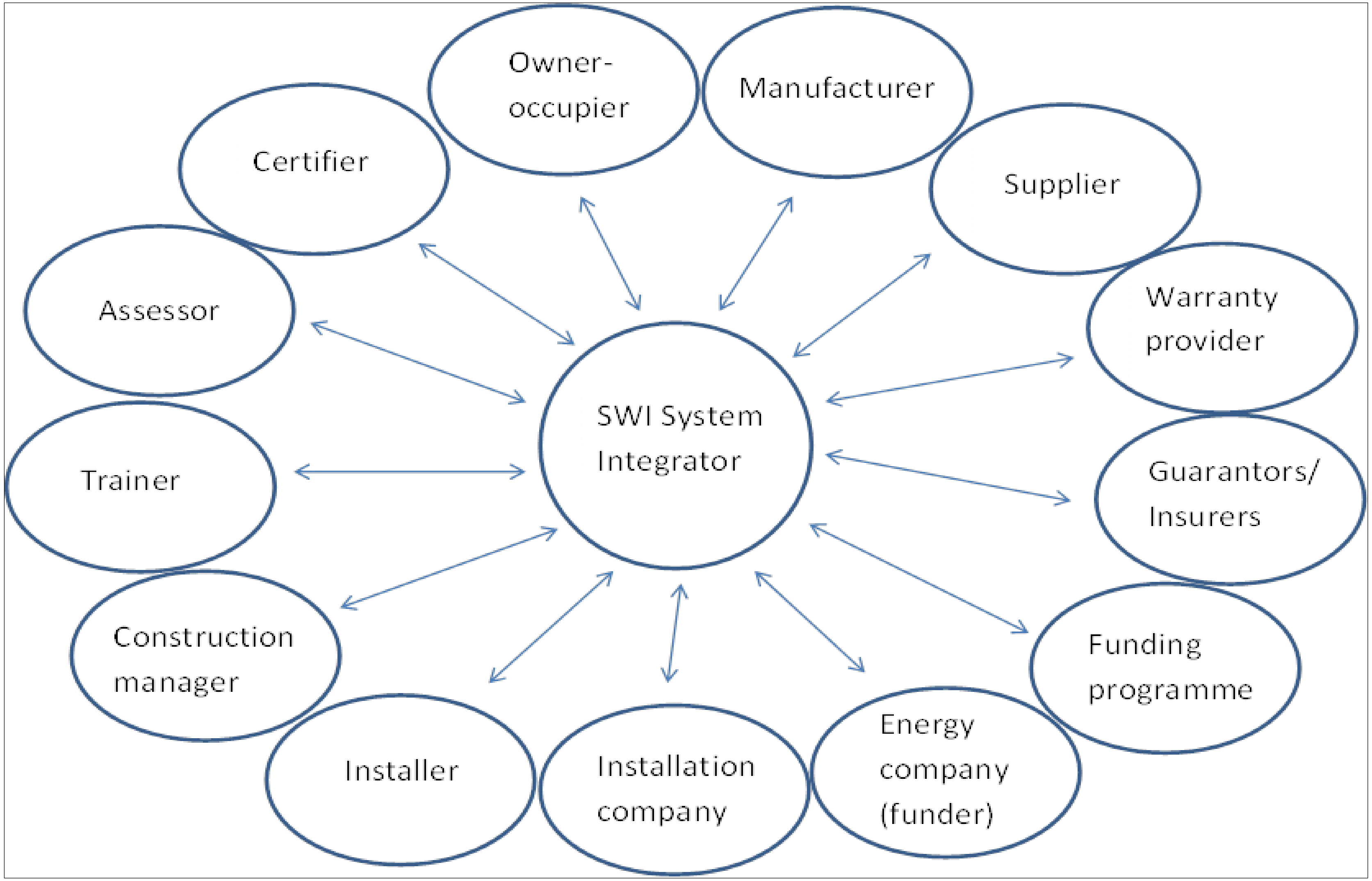


Figure 84: SWI system integrator positioned against all other SWI actors

Table 9: Role of SWI system integrator in relation to all other actors

	Services from SWI system integrator
Owner	Manages communication throughout project
Funder	Consults with technical staff in specification, reports to funder
Funding overseer (e.g. CESP or ECO)	Named principal contact, serves as intermediary between principal contractor and funder/broker
Installation company	Serves as liaison, approves changes in specification and detail solutions, verifies appropriate installation
Surveyor(s)	Collaborates to ensure pre-survey is adequate, directs further surveys as required
Installers	Monitors installation quality, identifies gaps in training, collaborates to ensure adequate skill and knowledge
Warranty provider	Notifies relevant parties if warranty conditions are jeopardised by practice
Guarantor/ insurer	Notifies relevant parties if guarantee/insurance conditions jeopardised by practice. Contact for auditing
Insulation manufacturer	Collects relevant data and specifications from manufacturer. Offers feedback to manufacturer
System supplier	Collects relevant data and specifications from supplier. Offers feedback on product and carding/training
Construction management	Ensures SMs and CMs are aware of correct specification, consults on change orders, liaises between CM and various trades and professional roles, serves as general 'technical consultant'
Trainer	Monitors training, identifies areas for improvement for first and second tier training, feedback to CITB and providers
Installer certifier	Monitors assessment process, feedback to CITB and funding overseer

9.5.6.4 Pathways to realisation

Bresnen (2013, p.740) argues that the authors in the Building Research and Information 'New Professionalisation' issue (2013, Volume 41, Number 1) (see Section 3.2.2.2) tend to point to the "differentiation and division of labour amongst the building professions as a major constraint" to meeting the sustainability agenda. He asserts that this displays a "tendency to ignore or downplay a key dynamic in Abbott's approach – namely, the notion of jurisdictional contestation and negotiation…" and asserts that this is "crucial…to understanding the factors enabling and inhibiting… collaboration…towards a 'new professionalism'" (2013, p.737). He points to CoP literature as an example of work which "emphasizes not only the challenges of inter-community collaboration, but also the within-community and inter-generational conflicts that can be engines for change…" (2013, p.739). Bresnen argues that propagating a 'new professionalism' must be "distilled from, and instilled in" (2013, p.740) the practices of professionals and shared across communities of practice.

It is difficult, however, to see that the SWI industry will address current failures without intervention. Many actors in this research displayed either unawareness of its failures or reluctance or defeatism in the face of reform. Bresnan describes that CoPs can be engines for change. The danger of group-think in CoPs as pointed to by Fischer (2013, p.203) has important relevance here and inertia may be difficult to overcome. Equally problematic, observation suggests that the SWI CoP is highly fractured by the industry's siloed structure and because of its poor mechanisms for knowledge exchange. If the industry is not sufficiently motivated to change, and lacks the cohesiveness to form a collective intent to adjust, then without intervention the only pathway to change is through much slower processes of jurisdictional contestation giving way to gradual metamorphosis.

The integrator concept has some relevant precedent in construction procurement. The 'Soft Landings' approach extends the temporal boundary of projects past completion and allocates additional responsibilities and accountability for performance to designers and constructors. Under the Government Soft Landings (GSL) programme, a 'GSL Champion' is nominated and is responsible for "asking the right questions of the construction team and the operation team" (Manning 2013). 'GSL Champion' is not a defined occupation, but as a concept it has close parallels to the 'integrator'. The intermediary role in ensuring performance targets are met during and after construction provides a useful model.

The element of post-completion commissioning and inspection for which an integrator might carry responsibility has some precedent in the regular inspections most homeowners have for heating systems, water treatment, air conditioners or similar installations.

The financial cost of the integrator role would need to be met by one or more parties, but significant savings or security of investment could be expected in return. This is similar to Soft Landings contracts, in which a client pays an additional cost but ultimately wins added value in return. So, who pays? In the current reality, the 'client' in most senses is the energy company; yet under future policy instruments, this may shift. Therefore, it seems sensible to place direct cost of the integrator with a more 'static' party. Principal contractors reported in this research that their profit margins were already restrictive (Section 8.3.1), so for them to bear the cost of the integrator would likely require additional funds from their clients. There are already indications that cost limitations have had real impacts on quality (e.g. insufficient budget to relocate gas services or insulate below DPC). This suggests that the policy instruments which mobilise SWI need to allow more money to flow to the contractor. Until this occurs, the contractors are unlikely to assume added costs unless compelled to do so by contractual requirement. Ultimately, all parties stand to benefit from the integrator role and it is likely that wherever the direct cost is borne, influence on the role will flow in return. Whichever party (or parties) pays the direct cost, it should be ensured that the integrator's value to projects is not undermined. Ostensibly, the party with the greatest interest in minimal performance gaps is the policy programme, while the party most concerned with limited unintended consequences is the insurer or underwriter. Because the benefits are shared by all parties, an amortisation of cost seems appropriate. This might be directed by policy programmes with the oversight of insurers. Clearly, the indications from this research that surveyors and auditors employed by insurers are not currently providing reliable 'checks in the system' suggests that policymakers may have a role in ensuring that pressure to reduce the cost of the integrator role does not lead to comprised functionality.

The realisation of a new role within SWI will certainly not be made without resistance. Against the forces of inertia and conservatism, space for the system integrator would require negotiation. The legitimacy of new professions within retrofitting, Nösperger et al. argue, can be understood in six different forms (2011, p.1374). These include 'professional-based legitimacy' (does the new group fit into the existing system?) and 'technical competency' (does the group possess "relevant thermal and technical competencies"?). Crucial in the context of SWI, the authors also point to 'policy-based legitimacy'. It may be that simply by enacting the requirement for a new certificate or process, an evolution in policy instruments could create space required for this new role. This, however, presents its own stark challenge; this project has highlighted issues of siloisation within government, faltering commitment from current political leadership, and the slow progress to date of CESP and ECO in driving changes in industry (e.g. auditing and management requirements). The alignment within government and between government and industry required to drive creation of system integrators through policy -- and the sheer progressiveness of intent -- would require a commitment to reform which has not yet appeared in relevant policy.

A further challenge – but also a potential opportunity -- is presented by the imperative to pursue integrated retrofits, which offer many advantages over single-measure projects. Literature and this research suggest that interaction with other actors in integrated retrofits will be more successful if negotiation at the boundaries of SWI is supported by a new professional role. Marrying the complexities of the SWI actor network with those of other RMI industries can only be made smoother by the presence of a highly trained intermediary.

9.6 Summary

The discussion presented in this chapter has examined research findings against previous research and broader theoretical backgrounds. This has shown the significance of findings to a wide range of topics. This reflects the complexity of findings and the variety of associations to broader contexts.

The final chapter contains the conclusions drawn from this thesis.

10 Conclusions

10.1 Overview

This final chapter begins with a review of the research aim and main findings. It then describes the implications and significance of the research in relation to a range of issues. This is followed by a delineation of the limitations of this research, before the chapter concludes with recommendations for further research and a final reflection.

10.2 Research aim and main findings

Research began with a broad focus on anecdotal reports of poor SWI practices. It aimed to contribute to strategy for improving the delivery of SWI by understanding how 'quality' is situated in practice and the diversity of factors which form the context of practice. Work was undertaken against a significant knowledge gap and so there was little previous research to challenge, verify, or expand upon. The foremost task was to develop questions and theoretical understandings iteratively as discovery unfolded.

Ultimately, work has focused observation and analysis on a relatively small subset of the industry from which it offers a form of instrumental (c.f. intrinsic) case study (Stake 2009). This work has offered a number of new theoretical explanations for current trends.

From the outset, a state of change in the landscape was identified; this was correlated to dramatically increased rates of retrofit driven by government policy. In final analysis, it appears these changes have not yet coincided with cause for appeasing concern about poor build-quality and performance gaps in SWI retrofit.

It is axiomatic that incautious installation and specification presents certain implications for robustness and value in SWI. Review of literature has outlined a wide range of risks from poor practice; these include performance gaps and unintended consequences related to moisture ingress, vapour accumulation, fabric degradation, mechanical failure, reduced service life, aesthetics defects, life cycle cost, life cycle environmental impact, and overheating. In large part, the understanding of 'how' to mitigate these risks – of 'how best' to insulate solid walls -- can be found in academic research (though clearly with significant immaturity in some areas).

This research has measured practice against a multifaceted definition of 'quality'. Quality has come to reflect not just the absence of unintended consequences, but the presence of benefit in a range of externalities. It reflects not only the outcome of SWI projects, but also the process of deploying retrofits.

Numerous examples of problematic practice in installation have been reported in this work. These emerged consistently across a range of settings. In parallel, research has examined a number of potential influences.

Expertise and understanding of the scientific principles of SWI across first and second tier actors were inconsistent but generally remarkably limited. Training and professional development of installers was studied as an exploration of the potential to explain this observation. This highlighted a range of issues which warranted further study including: competency of trainers; suitability of training curricula; the history of vocational training and implications for trainers and training institutions; engagement of trainees; and obstacles to more successful formal training. Observation and analysis indicate that formal mechanisms are generally not intended to deliver technical content and do little to facilitate meaningful understanding of SWI principles or risks.

Qualification assessment was a noteworthy focus in analysis, although only limited observation of the assessment process was possible. Basis for findings included extensive discussion with two trainers during participant observation of NVQ training and with one NVQ assessor, in conjunction with discussion and observation including several figures from industry bodies, the CITB, DCLG, and a number of certified installers. Findings suggested that certification of installers – for a number of reasons – is not yet a reflection of technical or practical competency.

Organisational knowledge management and knowledge pathways were a further area of examination. Observation here suggests that very few structured approaches exist in the industry and that first and second tier actors work to a large extent in siloed, disperse settings in a poorly integrated industry, which presents significant obstacles to knowledge exchange.

Moreover, the CoP which might be understood in the context of UK SWI appears poorly bonded and does little to connect those who hold scientific understanding with those who deploy or manage deployment of retrofits.

Management of retrofit projects by primary contractors became an area of focus for observation as the critical role it played in shaping retrofit quality became clear. Through extensive observation, contract and site managers were understood to influence projects as much by their lack of control as by any intentionality. This appeared rooted in an absence of training or history of advanced management systems or methods in the industry. Furthermore, although managers held ample procedural knowledge and 'site proficiency, many reflected the same shortcomings in understanding SWI principles and risk as first tier actors.

Motivation, pride, identity and aptitude were among a range of factors related to ‘ability to do’ and ‘willingness to do’ which emerged from this research. This observation bordered on idiographic and was at the boundary of what was ‘knowable’, particularly given the research approach. Nevertheless, these factors were unquestionably relevant to the delivery of SWI in the majority of observations and formed a component of analysis.

The agency of technology in affecting SWI quality was similarly a critical issue, though often difficult to penetrate fully. Participant observation as a trainee and installer, coupled with extensive observation and site inspection offered valuable insights to a range of limitations and influences roots in technology. A range of factors represented by the umbrella term ‘buildability’ were identified as relevant to SWI quality.

Government policy forms the dominant driver of SWI and the nature of its instrumentation in programmes like CESP and ECO was identified as a principal factor of quality in this research. Its intentional and inadvertent impacts reach not just the processes of installation and specification but broad actor networks. Policy appeared to drive progressive change but equally underlie systemic problems at individual and organisational scales across installation, training, certification, insurance, regulatory control, the wider supply chain and nearly all sites in observation.

Opportunities for improving quality have been presented in discussion of the majority of findings. These include mechanisms for overcoming siloisation, improving knowledge exchange, tightening controls on the processes of delivery, making training and certification more robust, retooling policy and aligning policy bodies and industry toward common aims.

10.3 Significance of findings

There is at the end of this research some cause for hope. Although increase in rates of retrofit during the course of this research was dramatic, the current government has faltered on continuing to push SWI. The consequences of this for the environment and for people are severe. Nevertheless SWI is an increasing focus in the retrofitting industry (Figure 85) and a renewed push is inevitable if carbon and energy targets are to be met. The current situation presents a fortuitous opportunity to consolidate lessons learned in recent years. A recent review of SWI by industry experts noted (CoRE Fellowship 2015, p.3):

> Achieving scale without ensuring quality will be counter-productive but the existing roll-out is so slow that existing unintended consequences are not so widespread that they should lead to immediate panic. The tipping point will come at the point of significant upscaling of the sector, and it is unclear when this will be.

Figure 85: Photograph showing talk on solid wall insulation at Ecobuild 2014 event

In many ways, the industry repeatedly failed to improve practice. This, however, appears largely due to inadequate training, support and structure. To a great extent, prior failures have been 'sins of omission, not of commission'. Yet this characterisation makes the failures no less concerning; the system of delivery must be optimised in order to reach targets without raising detrimental impacts. The inadequacies of knowledge exchange, formal training and certification programmes, management practice, motivation and identity and industry structure are such that intervention rather than laissez-faire reform are called for. The urgency of improvement and the consequences of continued failure are simply too great.

Prior models of historical groundswells in technology deployment -– such as electrification, railroads, wartime industry and space exploration -– show that investment of billions in infrastructure and technology development can be successful when government and industry work in tandem to overcome limitations in capacity and capability.

For installers, this research suggests a need to accept responsibility and find motivation for pursuing optimum practices. A deeper commitment –- and 'obsessional energy' (Sennett 2009) –- and pursuit of excellence is necessary. This is not just a call for installers to redouble their efforts for the sake of safer more effective retrofits. System of professions theory and history itself shows us that if performance gaps and unintended consequences are allowed to propagate, the 'SWIer' may lose legitimacy.

Policy bodies and government leadership have been deeply remiss in allowing instability to affect SWI industry. Funding streams have faltered repeatedly across energy policy instruments and this has led to a crippling of industry. Without security in their profession, installers cannot be expected to develop identity or commitment. Neither can we expect installers or companies to invest in training and certification. In turn, the individual trainers and assessors and the organisations which employ and support them will not commit to continued improvement.

The domino effect of policy continues. With faltering commitment from the top, it is not only that investment is unavailable during periods of low funding. Without stability, investment by manufacturers, primary contractors, suppliers, trade groups, surveyors and myriad other entities who are directly involved in SWI will be conservative and therefore inadequate for realising the necessary improvements. This research has pointed to numerous areas in which vastly greater investment is required. Policy needs to be aligned across government and industry needs to build trust in that policy for there to be any chance of real improvement.

In the meantime, there are steps for all actors to take. Just as installers must adapt to the new reality that the legacy of poor practice cannot continue, many others need to take ownership of this problem too. Construction management appears to be largely conducted by SME contractors and without formally trained staff or best practice standards. Until expert construction managers are a part of SWI retrofit projects, it is difficult to see site practices and project impacts will improve substantially; this points to the need for SWI- and retrofit-specific training for construction managers. Likewise, surveyors, building control officers, auditors and parallel trades need training in order to respond appropriately to the SWI agenda.

Manufacturers, specifiers and designers might recognise in this research opportunity to improve buildability of materials and designs. Buildability has been defined in relation to a host of attributes and this research suggests many are lacking in currently employed technology. The agency of technology in SWI should not be overlooked.

Mechanisms for improvement must be leveraged by intervention on a number of fronts. However change can be effected not only through top-down approaches, but from bottom-up ones too. This is likely to be a positive feedback between the two. If intervention and structured approaches create more robust knowledge pathways, reduce siloisation and forge professional identity and pride, a reciprocating cohesion and healthier CoP will begin to achieve must of the needed improvement across the landscape.

The boundaries of this CoP are only emerging. Integrated retrofitting is in many ways the elephant in the room in this research. Observation focussed on single-measure projects simply because they dominated the research setting. Integrated retrofits and refurbishment will not only shift the boundaries of the SWI CoP, it may transform professional identity and role definition altogether. Intra-industry dynamics may change beyond recognition from the current siloed, disperse and largely inexpert landscape. The multi-skilling agenda, and most centrally the system integrator concept highlighted by this research offer ways to improve SWI practices. They also offer potential answers to the question of how SWI can be successful within the integrated retrofit paradigm.

The cost and impacts on sustainability and resilience of continuing to get this wrong will be enormous. Conversely, the potential benefit realised from improvements should incentivise all actors to commit to getting things right. Whether measured as life cycle or capital cost, environmental or social benefit, opportunities for training and stimulation of local economies – whatever the externalities may be – the costs and impacts at stake have sizeable implications across society. It is not hyperbolic to state that every individual will be affected by the success or failure of SWI rollout.

The underwriting of insurance which currently provides the safeguard to investment in SWI may need to be reconsidered. Many participants expressed doubt that it will be able to address the potential fallout of current practices. Guarantors, energy companies and funders, and policy bodies need to ensure that auditing, inspection and risk assessment are robust and that guaranty agencies are adequately prepared to fund rectification of future problems.

Finally, this project highlights an urgent need for continued research. The certainty of conclusions that has been reached here is not adequate. To understand more fully how vulnerability to performance gaps and unintended consequences can be purged from the current system of deploying SWI will require concerted effort. This research presents a broad range of directions for future inquiry. A research agenda which builds on current evidence is urgently needed. This might be informed by the Zero Carbon Hub's recent analysis of performance gaps in energy projects and its call to develop strategy by evaluating density of evidence and potential relevance to performance (2014, p.3) (Figure 86).

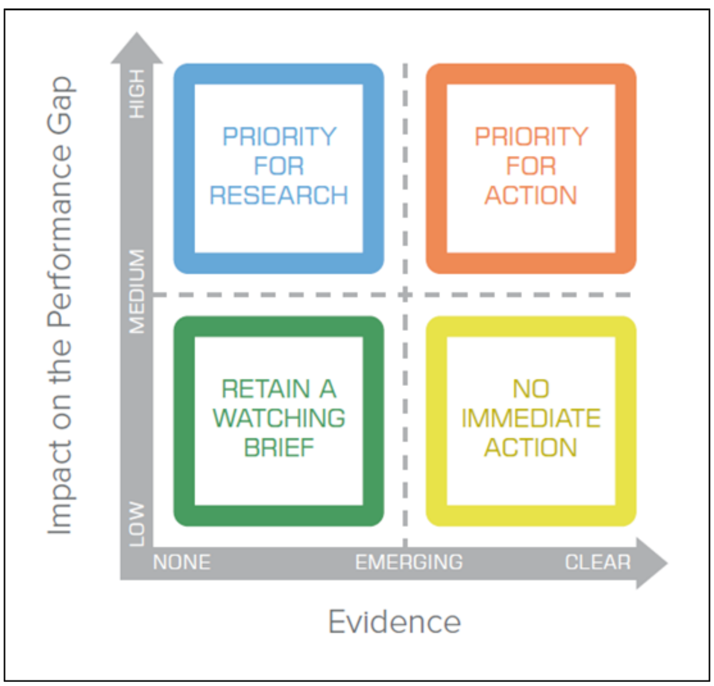


Figure 86: Implication for action of relationship between evidence and performance gap impact (Zero Carbon Hub 2014, p.3)

10.4 Limitations of research

This work has developed new questions and theoretical explanations in response to phenomena observed using qualitative methods. Uncertainty is inherent in this approach and the research contains a number of relevant limitations.

The boundaries and scope of this research have necessarily been limited in response to available time and resources. This in part is reflected as limitation in duration and intensity. Observations were necessarily made within a relatively small subset of the wider setting. To a certain extent, it also was necessary to work within geographic limitations; nevertheless, wherever possible sites and participants were included regardless of their physical location.

Because recruitment followed a 'snowballing' pattern, the selection of participants was partially determined by change or in response to availability and access. This presents inherent participant bias.

Observation of retrofit projects was essentially limited to area-based projects, largely delivering single-measure EWI in 20th Century system build construction. These projects appeared to comprise the vast majority of contemporary SWI retrofitting and certainly dominated the work encountered across all phases of research. Despite this, findings in the context of different building typologies, SWI specification project funding and administration, or in integrated retrofit projects may differ significantly.

These issues shape the ecological validity of this research. Many of the realities of the subset of the industry which was included in this research will likely be paralleled in other contemporary settings. Nevertheless, the 'petite generalisations' (Stake 2009, p.93) in this research cannot necessarily be transferred to the wider SWI 'world'. There are clear limitations here in generalisability, reproducibility, and validity of contextual understandings.

Methods were selected to enable collection of 'rich' data and to develop understandings of the topic that were 'close' to reality. This entailed the collection and analysis of large amounts of data. This is typical of work of this nature. This project has fused several traditions of method and analysis to produce an appropriate and robust approach; however critics may rightfully point to degrees of subjectivity and reflexivity which are inherent here (Herbert 2000). This was moderated by the employment of coding and 'theoretical saturation', verification strategies and constant comparative method (triangulation). Qualitative work is often the indefinite and woolly member at the research table. At its extreme, it appears unsystematic, messy and edging on artistic. This research has endeavoured to avoid this extreme and to capture a rich and meaningful interpretation of the SWI landscape. Nevertheless, neither observation nor analysis are necessarily reproducible (Spencer et al. 2013) and it must be recognised that others might have asked different questions or drawn different conclusions at various stages of discovery.

Moreover, this work takes place in a limited research context. The work has been undertaken to complement other primary research and secondary analyses, but it must be recognised that pre-existing work was limited.

10.5 Recommendations for further research

This project has built on significant scientific and theoretical research and owes much to the work of others. It also takes some of the first steps toward improving understanding of SWI retrofitting as it occurs on the ground.

The findings of this research have suggested a number of potential paths for future research. Deepening the understandings of how unintended consequences and performance gaps *actually* occur and expanding the body of work that has preceded this research are important directions for future efforts.

This research suggests that the expert opinion that practices in industry are generally poor deserves further research. At the beginning of this project, this opinion was widely postulated but very little published record existed. The observations of this research, and emerging opinion from other sources, are only beginning to provide the evidence needed for further action. Although there are minor indications of some cause for optimism about changes in industry, it is clear that practices have vast scope for improvement. A diversity of quantitative and qualitative approaches to improving the understanding of root causes of poor practice and the correlations to performance-in-use and sustainability in SWI or in parallel settings is warranted.

Many contexts of SWI were not included in the focus of observation here. These include IWI, SWI in traditional construction, historic and historical buildings, non-UK contexts, small scale projects, and integrated retrofits. These all present obvious directions for future work.

A major question left unanswered by this research relates to extent of failure in previous and contemporary SWI retrofitting. Evidence so far is woefully inadequate. Much larger samples and more comprehensive testing and monitoring are needed to understand the magnitude of the problem already created and the implications of current practice.

This research has been informed by a long history of socio-technical, organisation, and multi-disciplinary research of energy and the built environment. The application of research method and methodological approach to SWI – while only a modest innovation – has enabled rich findings. Future research with similar approaches in related contexts will likely realise comparable benefits.

It should not be overlooked that this research gives a 'voice' to the 'middle' actors in industry whose perspectives often go disregarded. Further research of these actors is called for not just in SWI retrofits but in the many parallel applications of energy refurbishment and LZC construction.

Issues of motivation, understanding, knowledge transfer, pride and professionalisation in SWI that have been highlighted here all deserve further attention. This would also be an interesting focus for further work in energy refurbishment, LZC construction and RMI contexts.

Within the policy realm, this research has shown that siloisation has particularly detrimental potential effects on retrofit delivery. Policy research or situated research in this context seems vitally important. Furthermore, the numerous shortcomings in policy instruments and the artificial pressures they exert which were observed in this research appear to be one of the dominant forces shaping SWI quality. To support continued improvement, policy instrumentation will need to be made more intelligent, more responsive and more progressive. Further research could examine strategies for improvement, obstacles, and models of success outside the UK. Likewise, the implications of faltering government action to drive SWI appear significant for employment, retention, training, and professionalisation. Firmer evidence of the impacts of cycles of boom and bust in policy-driven retrofitting is needed.

Training, assessment and certification programmes have been shown to exhibit many shortcomings. Further research could examine more closely the impacts of this, develop understanding of root causes, and identify mechanisms for and models of improvement.

Innovation in SWI technology is clearly a research area which needs deep investment. Improvements in performance, cost, environmental impact and buildability would be hugely important to improving SWI performance in reducing risks.

Construction management has for many years been criticised for lagging behind other sectors. Evidence suggests that management in RMI and in energy retrofits is particularly poor. This remains an under-researched area. It is important to understand the impacts of practices and the opportunities for improvement, and to imagine the adoption of practices from system-building and other sectors to the context of area-based refurbishment.

Many topics of supply chain management (SCM) have fallen outside the focus of this research. Research of SCM in construction, particularly in the contexts of retrofitting and area-based retrofitting, can offer many lessons from manufacturing and other sectors. Particularly in light of the challenges presented by large scale rollout of SWI, identifying the impacts of various SCM practices and outlining opportunities for improving practices seem particularly important.

Finally, the potential value of exploring further the multiskilling agenda and the system integrator role on SWI projects has been raised by this research and further work toward envisaging and implementing these concepts in industry is urgently called for.

10.6 Reflection

During the period of research, SWI in the UK burgeoned. This was an encouraging development in light of the many potential benefits it offers. Domestic SWI is easily understood as a mechanism for reducing the UK's dominant source of GHG emissions. It also offers vitally important benefits related to reduced resource consumption, improved thermal comfort and occupant health, reduced expenditure on heating and cooling, and reduction in fuel poverty.

The latent risks of poor installation practice and specification are extensive, and the costs -– financial and otherwise -– associated with failure are enormous.

At the beginning of this research, in most regards SWI was found within a nascent and understudied industry. Despite some degree of change, this characterisation remains largely relevant.

Observation suggests justification for long-standing concern about high rates of inappropriate specification and installation. It is likely that practices have led to significant performance gaps and other unintended consequences across many thousands of installations. In light of the prospect of continued retrofitting driven by government policy, it is critical that the propagation of poor practice is stymied as quickly as possible. As homogenous co-located projects run out, and as 'low hanging fruit' gives way to more challenging historic and traditional constructions, challenges to industry will become even starker.

It is hoped that rather being read as a jeremiad, this thesis will provide useful signposting to opportunities to improve practices in SWI.

It is vital that the government delivers on its targets for GHG reduction and improving the plight of millions who live in fuel poverty. This will require alignment of multiple government bodies with industry to ensure that notional reductions are actually achieved. Continued failures in delivery of SWI and propagation of risks of unintended consequences present an untenable cost-benefit ratio.

If it can curtail poor practice, industry – which includes installers, manufacturers, suppliers, trainers and assessors -- stands to make substantial gains by capitalising on the momentum of government support for SWI. This will be jeopardised by collective failure to advance practices.

The old maxim 'easier said than done' could not be more germane.

To date, advances in practices have been achieved largely through policy instruments, which have essentially imposed incremental improvement on quality management from industry. This may continue to be an effective mechanism for progressive reform in installation companies. In other areas, government has been less successful. Its arms-length relationship to industry training in which industry sets its own agenda and polices its own success has led to decades of underachievement. Studying the successes and failures of CESP and ECO -- particularly in light of the failure of the Green Deal programme – it appears that there may be insurmountable limitations of a neo-liberal approach to driving retrofit. Effective policy which will realise the full benefits of retrofitting the millions of homes yet to be treated is critically important. Siloisation within government and the challenges of a fractured industry dominated by SMEs and microenterprise present a tremendous challenge to this.

The ripples of failure will be felt widely. The implications of business as usual extend far beyond a failure to meet energy targets. This thesis has shown close connections between policy instrumentation and diverse issues of industry practice, identity and motivation, aptitude, learning, training and certification, the health of professions and numerous aspects of social, environmental and economic resilience and sustainability.

To orientate industry and government toward success will require answering many more questions than has been achieved here. The limited history of SWI retrofits in the UK has led to practices remaining under-researched. This thesis has only begun to raise and answer the necessary questions.

Appendix A -- Definitions and terminology

A.1 Enabling works

'Enabling works' refers to the variety of tasks required to install SWI which falls outside the remit of the installer trade. This includes removal and reinstatement of services, rainwater goods, fitted furnishings, abutting structures, garden gates, and any of a range of fixed or unfixed items in order to install SWI.

A.2 Installers, first and second tier actors

'Installers' is used to describe professionals who are responsible for fitting SWI. This process includes cutting insulation material, placing it against the wall, fixing or adhering, and installing render, drywall or other outer protective layers.

'First tier actors' refers to installers but also those tradespeople who carry out enabling works.

'Second tier actors' refers to the wider group of professionals directly involved in delivery of SWI retrofit. This group includes site and contract managers and surveyors. It does include company directors, auditors, trainers, assessors or manufacturers.

A.3 Milieu and work-world

The term 'milieu' (or 'SWI milieu') is used in this thesis to encapsulate the complex system of organisations, individuals, technologies, socio-technical constructs, political contexts and sociological forces that directly or indirectly influence SWI installations. 'Work-world' is used to describe the boundaries within which professionals carry out their duties. It connotes the rules and norms, interrelations with parallel occupations, professional duties and frameworks within which individuals work.

A.4 Permeance versus permeability

Distinction between 'permeability' and 'permeance' should be understood. The former is commonly used to describe the capacity of a material to allow moisture to transit through it. In more apposite usage, it refers to the rate of vapour transport across a unit area and unit thickness, at a unit vapour pressure difference. Permeance, meanwhile, is the rate of vapour transport across a unit area at a unit vapour pressure. In other words, by dividing a material's permeability by its thickness, the material permeance is obtained. As such, permeance is the measurement by which the resistance to moisture transmission of products or assemblies can properly be compared.

Nevertheless, 'permeability' is almost ubiquitously used to describe permeance in common usage – and even many professional settings. As such, a degree of interchangeability can be assumed in this thesis, particularly in quotations of research participants from non-scientific backgrounds.

A.5 Retrofit, solid wall insulation retrofit, refurbishment, renovation

'Retrofit' is used in this thesis to describe SWI, but also any application or instrumentation of material or systems to achieve a reduction in operational energy demand or greenhouse gas intensity, or introduce a renewable source of energy. Prior to government programmes driving SWI retrofitting, it was predominantly funded in small-scale private contracts. This thesis examines SWI retrofitting almost entirely in the context of area-based and multi-site projects delivered with the financial and programmatic support of government drivers. Unless noted otherwise, 'SWI retrofitting' refers to this contemporary context. 'SWI' is often used to refer to insulation fixed to either the external or internal face of a wall, whether it is constructed of solid masonry or not.

'Refurbishment' connotes the general processes of cleaning, repairing, or upgrading building fabric, and is used to refer to undertakings aimed at improving the aesthetic, desirability, or monetary value of a property. 'Renovation' carries similar connotations and is used to describe the process of upgrading a property in line with modern standards. 'Maintenance' is used to describe processes of cleaning, painting, or general works in order to keep a building element in good condition and ensure its optimal lifespan.

A.6 Repair, maintenance and improvement

'Repair, maintenance and improvement' (RMI) is a categorisation within the construction industry. This was historically used in the collection of statistics by the UK Government, however the Office for National Statistics now uses 'repair and maintenance' to analyse construction output in housing (Davies 2013). It describes this usage as including "…repairs, maintenance, improvements, house/flat conversions, extensions, alterations and redecoration on existing housing" (Office for National Statistics 2007, p.8). In this thesis, RMI refers to the broad sector of industry in which SWI is located. In some discussion, RMI is used to refer to energy related projects within the RMI sector.

A.7 Small and medium-sized enterprises (SMEs)

Various definitions of ‘small and medium-sized enterprises’ (SMEs) are used by UK and European governments.

The European Commission in 2003 defined SMEs in relation to the total number of employees in a commercial organisation and either its annual turnover or balance sheet total (European Union 2003; European Commission 2005). These same measures are used to define ‘micro- enterprises’. A firm within a larger group may or may not be defined in relation to that group’s characteristics. The values provided by the Commission are shown in Table 10 (European Commission 2014).

Table 10: Criteria provided by European Commission to describe 'small and medium-sized enterprises' and 'micro-enterprises'

Company category	Employees	Turnover	or	Balance sheet total
Medium	<250	≤ € 50 m		≤ € 2 m
Small	< 50	≤ € 10 m		≤ € 10 m
Micro	< 10	≤ € 2 m		≤ € 2 m

UK Government departments use varying definitions. The HMRC (in determining Research and Development Tax Relief) define SMEs as having less than 500 employees and a £100 million annual turnover. The Department for Business defines an SME as an enterprise with less than 250 employees. Companies House identifies small enterprises as having fewer than 50 employees and less than £6.5 annual turnover, and medium enterprises as having more than 250 employees and £25.9 turnover. Elsewhere in UK governance, the European Commission differentiations (Table 1) are used (Welsh Government 2009).

Unless quoted from an external source, where a descriptor is used in this thesis, the European Commission’s 2003 definition of SMEs and micro-enterprises is implied.

A.8 Trades and tradespeople

‘Tradespeople’ is used to describe any manual worker, but generally one working within the bailiwick of the SWI retrofit industry. ‘Tradespeople’ is used to describe profession, not to connote proficiency.

‘Trades’ may refer to the general construction trades or to the professions of SWI installers, or related work of electricians, gas-fitters, plumbers, satellite and internet utility installers, tilers, decorators, plasterers and renderers. Neither term is used to refer to site supervisors, quantity surveyors or other management positions, or to describe retailers of building materials.

A.9 Traditional and non-traditional construction and system-build houses

‘Traditional construction’ in the UK refers generally to masonry (or sometimes to masonry and timber) construction techniques which were dominant until the First World War. It includes solid wall masonry construction (1800s to 1950) as well as cavity wall masonry construction (which appeared around 1900 but became dominate around 1935). The term is applied to brick/block or rendered block/block cavity construction even if built today.

‘Non-traditional construction’ typically refers to metal-, timber-, or concrete-frame structures, or in-situ concrete or panelised construction built between 1918 and 1980. ‘System-build’ houses describe standardised, often modularised construction either entirely prefabricated or built with methods akin to ‘on-site factory’ production. These are typical of the post-First World War and post-Second World War building booms and are often criticised as displaying poor build-quality or substandard specification and being prone to problems including material corrosion or carbonation.

Appendix B -- Relevant legislation, regulation, policy and policy instruments

The vast majority of SWI retrofitting which has occurred during the period of this research has taken placed under programmes stimulated by government policy which sits within a broader hierarchy of national and international legislative and policy frameworks. To provide a detailed overview of these frameworks is outside of the scope of this thesis. A brief overview is provided in Table 11.

Table 11: Legislation, regulation, policy and policy instruments relevant to solid wall insulation in the UK

	Scope	Source of funding	Stated aims	Relevant legislation
Energy Company Obligation	UK	Energy companies	• Carbon emissions reduction • Home heating cost reduction	•
Community Energy Savings Programme	UK	Energy companies, administered by DECC	• Carbon emissions reduction • Fuel poverty reduction	•
Arbed (Phase 2)	Wales	European Regional Development fund (ERDF) and Welsh Government	Work in the most economically deprived areas of Wales to: • improve energy efficiency of at least 4800 homes; • reduce GHG emissions; • stimulate supply chains;	

			• provide training; • local workers; and • stimulate local employment and economies	
Carbon Emissions Reduction Target		Energy companies	Carbon emissions reduction	• Section 33BC of the Gas Act 1986 • Section 41A of the Electricity Act 1989 • Climate Change and Sustainable Energy Act 2006 • Electricity and Gas (Carbon Emissions Reduction) Order 2008 • The Electricity and Gas (Carbon Emissions Reduction) (Amendment) Order 2010
Green Deal (first phase)	UK	Occupant / bill-payer (through loans), overseen by DECC	• Improve energy efficiency, upgrade ageing stock • Reduce GHG emissions • Long-term reduction in energy-related expenditure	

B.1 CESP

The Community Energy Savings Programme (CESP) was a UK policy instrument which drove significant uptake of SWI. CESP existed under the Government's Home Energy Saving Programme and had an obligation period that spanned 01 October 2009 to 31 December 2012. Its purpose was to improved building fabric energy efficiency in existing homes of domestic energy users in low income areas of England, Scotland and Wales. It was funded through obligatory contributions from the country's largest gas and electricity suppliers (those with at least 50,000 domestic customers) and those electricity generators with a production of equal or above 10 TWh/yr or more in a specified three year period. (Ofgem 2013b)

DECC, which developed the policy framework and administered CESP, set an overall target for CO_2 emissions reductions of 19.25 million lifetime tonnes. The actual achievement through the programme was 16.31 million tonnes, or roughly 85 per cent of this target. In 491 schemes delivered under CESP, 293,922 measures were delivered in 153,464 dwellings. (Ofgem 2013a, p.1)

The programme was based on a 'whole house' approach, which promoted the adaption of multiple measures each home. Provision of mechanical or natural ventilation (which can mitigate some risks of SWI in certain contexts) was not provided by CESP (Ofgem 2013b). Loft insulation was a commonly installed measure, and its provision alongside SWI was incentivised by CESP (Ofgem 2013b, p.37). The programme incentivised a wide range of measures, which included insulation, fuel switching, renewable heat technologies, micro-CHP, and replacement of G-rated boilers. 5,002 IWI installations and 75,255 EWI installations were delivered under CESP. Aggregated carbon savings for all insulation measures (unadjusted for bonuses awarded in the programme) were 2,631 kt CO_2, or 57 per cent of total programme savings. (Ofgem 2013a, p.3)

Impetus was provided to treat maximum numbers of properties in defined areas (at least 25% of the properties in an area), based on the Income Domain of the Indices of Multiple Deprivation (IMD). It included the lowest 10 per cent of IMD-ranked areas in England, and the lowest 15 per cent in Scotland and Wales (Ofgem 2013b).

Technical monitoring was considered a key control on quality standards, though energy companies were required to undertake monitoring of just 5 per cent or more of each measure. Properties were inspected with the use of standardised technical questions developed by Ofgem (failures could be due to customer satisfaction, health and safety, legal or building regulations, or carbon savings). 8.7 per cent of SWI installations were technically monitored, with 1.1 per cent of monitored SWI measures failing. Ofgem commissioned independent auditors to audit all energy companies to assure compliance with CESP regulations. These audits combined on-site and desk-based audits; results reported by Ofgem included observations that technical monitoring by energy companies was in some instances slow to be implemented. (Ofgem 2013b, pp.39–40)

In its final report on the CESP programme, Ofgem reported (2013b, pp.44–45):

> Given that CESP was designed to promote the installation of specific measures in hard-to-treat properties, it was inevitable that some technical difficulties would arise. However, the number and complexity of technical issues encountered was unanticipated. These issues included:
>
> - Clarifying how the suitability of solid wall insulation systems could be demonstrated;
> - Formulating the criteria required to be met for energy companies to claim solid wall insulation as a means of insulating hard-to-treat cavities;
> - Establishing what starting U-values to use for the wide variety of construction types in the score calculations;
> - Determining how to calculate the savings for partial or 'non-standard' measure installations, where the unadjusted score was recalculated based on the proportion of the depth or area treated;
> - Calculating bespoke scores and assessing technical specifications for district heating connections and upgrades.

B.2 CERT

The Carbon Emissions Reduction Target (CERT) programme was administered similarly to CESP, and had a commitment period from 1 April 2008 and 31 December 2012. Unlike CESP, CERT was not solely targeted at low-income consumers, but instead solely at carbon emissions reduction from domestic buildings. Similar to CESP, it was funded by obligations on the nation's largest gas and electricity suppliers. The Gas and Electricity (Carbon Emissions Reduction) Order 2008 and subsequent amendments stipulated that CERT would reduce lifetime CO_2 emissions by 293 million lifetime tonnes. It also specified that 40 per cent of savings would be made in housing for people over 70 and on certain qualifying benefits, and 16.2 million tonnes of savings in households on certain low income benefits such as child tax credits. Of the 293.4 million lifetime tonnes of savings in CERT, 73.4 were to be made from professionally installed insulation measures. (Ofgem 2014b)

Prior to CERT, similar programmes were the Energy Efficiency Standards of Performance (EESoP) – which ran from 1994 to 2002 – and the Energy Efficiency Commitment (EEC) 1 and 2, which ran from 2002 to 2005 and 2005 to 2008.

B.3 Energy Company Obligation

CESP and CERT were replaced by the Energy Companies Obligation (ECO), which came into action in Great Britain at the start of 2013. Similar to these programmes, ECO obligates the largest energy suppliers to fund and deliver fabric efficiency improvements in domestic buildings. It has been designed in parallel with the Green Deal (see below), and has a specific target of vulnerable consumers and hard-to-treat homes.

ECO contains three separate obligations for energy suppliers: Carbon Emissions Reduction Obligation, Community Obligation, and Home Heating Cost Reduction Obligation. The Carbon Emissions Reduction Obligation targets hard-to-treat homes and measures which do not meet the criteria for full funding through Green Deal. SWI and hard-to-treat cavity insulation form the primary focus for this Obligation, but it also includes other insulation measures and connections to district heating infrastructure if they are included in packages that include SWI or hard-to-treat cavity insulation. The Community Obligation serves to provide insulation and district heating connection to low income areas; a sub-target requires that at least 15 per cent of each supplier’s action under this Obligation must be achieved in areas of low income and rural vulnerable households. Finally, the Home Heating Cost Reduction Obligation requires that energy suppliers provide heating technologies (such as boiler repair or replacement) to low income and vulnerable households. (Ofgem 2014a)

B.4 Green Deal

The Green Deal was instituted by the Energy Act 2011, and provides a ‘market-led’ approach to promoting energy efficiency improvements. A ‘soft launch’ of the programme was made on 01 October 2012, and a full launch was made in January 2013 (loans were available from 28 January). The programme provides a financing framework through which homeowners pay for improvements through energy bill payments rather than in upfront costs; the total repayment costs remain at or below pre-retrofit bill amounts (the ‘Golden Rule’). Measures covered by the Green Deal include SWI and other types of insulation, draught proofing, heating and renewables, or glazing upgrades.

The programme consists of Green Deal Providers, Green Deal Assessors, and certified installers. Financing is provided at open market interest rates through Green Deal Providers (private sector entities). An initial 22 Providers were enlisted, which included three of the Big Six energy companies. Green Deal Assessors are auditors who are trained to conduct home surveys in order to specify appropriate efficiency improvements through ‘Green Deal Advice Reports’. Significant information in these reports is commonly provided by the homeowner, including date of construction, type of wall construction (i.e. non-traditional or traditional), building occupancy and typical heating patterns, and pre-existing energy-saving measures. The Green Deal Providers typically arrange installation and provide financing, however the homeowner may pay for the work and use a Provider to arrange installation, or forego involvement of the Provider in financing or installation following issuance of the Advice Report.

ECO and Green Deal were launched in parallel, with ECO facilitating those measures that do not meet the Golden Rule (some cases of SWI) and to meet the needs of low-income households. Unlike for ECO, Ofgem has no explicit role in administrating Green Deal.

Oversight is provided by the Green Deal Oversight and Registration Body, which has been set up by DECC and operates on behalf of the secretary of state. The Consumer Credit Act is used to provide protection to borrowers.

To date the programme has evolved in two phases. In the first phase, which ran through spring 2014, homeowners were incentivised to participate through loan availability. This phase has largely been viewed as a failure due to the fact that a very low number of people enlisted (1,754 projects were undertaken). The second phase has utilised grants from a Government fund in order to incentivise broader participation.

The Green Deal Cashback Scheme, which was operated by DECC began in February 2013 and provided incentives for a variety of measures including SWI. Where 50 per cent or more of wall area was being treated, the Scheme initially provided £650 for SWI, which was increased to £4,000 on 13 December 2013. The Government had a stated aim of reaching 10,000 households by the end of 2013; however the number of enrolees at the end of May 2014 stood at just 2,828. Following the low uptake of Green Deal in the first phase, the Government introduced the Green Deal Home Improvement Fund (GDHIF), which opened to applications on 09 June, 2014. This greatly expanded the incentives provided by the Cashback Scheme, by providing up to £7600 of subsidy to any homeowner who was installing one or more approved measures in England or Wales. A maximum of 75 per cent of SWI costs up to £6000 was provided, or when accompanied by a second measure, 100 per cent up to a maximum of £1,000 (1,500 for home-movers). Six weeks after opening, on 24 July, 2014, the GDHIF was closed as the Government reported that all available money (£120 million) had been spent. The Government allocated £120 million to the GDHIF, which after a dramatic uptake in the several days following a warning that this allocation would be cut, was all spent by the closing date. In the final week of the scheme, 9,463 applications were received (reportedly worth roughly £70m); this was compared to 2,261 applications in the preceding week. At the time of writing, it is not known how many vouchers have been cashed in following application.

The Green Deal has been met with significant criticism from both industry and general media (e.g. Editor 2012; Monbiot 2013). This has centred on the high interest rates which were typical of early financing arrangements, low take-up during the first phase of the programme, and the perceived unpredictability of changes in the policy framework. The themes of certainty and continuity in policy are recurrent issues for many young industries, including SWI. A policy and public affairs officer at the UK Green Building Council, encapsulated the difficulty posed to the retrofit industry after the closure of the GDHIF in July, 2014, noting (Gosden & Winch 2014):

> The sudden and immediate closure of this fund is another setback for the energy efficiency industry because companies have specifically geared up to market and deliver through this scheme. These constant changes are not helpful to industry. We now need urgent clarity as to whether Government will bring forward any more money to ensure continuity of Green Deal work. This does demonstrate that we need long-term drivers, not short term pots of cash to avoid this continual cycle of boom and bust.

A representative from the boiler manufacturer Worcester, Bosch Group, echoed this sentiment, noting, "The tragedy is that, for once, DECC has come up with a scheme that works. It's a body blow and a triumph for short-termism" (Carrington 2014). Perhaps unsurprisingly, it was also echoed by the shadow energy minister Jonathan Reynolds, who stated: "This is a shocking act of incompetence. It will leave… an insulation industry in despair at the stop-start nature of this government's policy" (Carrington 2014).

B.5 Arbed

Arbed is a Welsh Government programme established in 2009 which is aimed at mitigating GHG emissions, reducing levels of fuel poverty, and advancing economic growth in Wales. The programme targets efficiency improvements in existing homes and has funded SWI as well as other measures. The first phase of the programme included £68 million which included Welsh Government funding as well as £32 million of leveraged funding from social landlords, local authorities, energy companies (through CESP and CERT), and other sources. This first phase funded over 4,000 SWI installations in area based schemes out of a total of 7,500 households reached by the programme.

The second phase of the programme began in May 2012 and includes £12 million of Welsh Government funding and an additional £33 million in European Regional Development Fund (ERDF) money. The programme has a stated aim of delivering 10 to 20 schemes annually, reaching at least 4,800 homes by the end of 2015 to achieve a minimum carbon reduction of 2.54 kt. Phase two of the programme is being delivered by two scheme managers: Willmott Dixon (north and mid Wales) and Melin Homes (south Wales) (Welsh Government 2014a).

B.6 Decent Homes

The Decent Homes Standard is a key component of the Decent Homes Programme which was introduced by the Blair government in 2000. The Standard introduces a minimum threshold for "decency" in social housing, establishing that it should (UK Government 2014):

- be free of health and safety hazards;
- be in a reasonable state of repair;
- have reasonably modern kitchens, bathrooms and boilers; and
- be reasonably insulated.

The Government declared in 2000 that all social housing would meet the Standard by 2010. As of April 2011, 217,000 council houses did not meet the Standard (UK Government 2014). To address this shortfall, £1.6 billion was provided by central government to local councils for the 2011 to 2015 period in order to fund improvements in the worst housing; an additional £160 was allocated for 2015 and 2016.

B.7 NEST

The Welsh Government has operated the NEST scheme since early 2011 in order to improve energy efficiency in vulnerable households. The programme seeks to reduce fuel poverty and provides advice and referrals to third party services as well as funding efficiency improvements. Improvements include EWI and a number of other measures. Home Energy Improvement Packages (i.e. funding for improvements) are available to owner-occupiers and private sector renters who live in F or G-rated homes where at least one person receives a means-tested benefit. The scheme is managed by British Gas, who sub-contracts improvement works to installers. Only a small proportion of the programme delivers EWI: this was approximately 1 per cent of 4,900 improvements in the April 2012 - March 2013 year and approximately 1 per cent of 5,825 improvements in the April 2013 - March 2014 year (Welsh Government 2013; Welsh Government 2014c).

B.8 Energy Performance Certificates

Energy Performance Certificates (EPCs) are required for all member states by the EU Energy Performance of Buildings Directive (EPBD), which was introduced in 2002, then came into force in 2007 and was recast in 2010. EPCs are an instrument for conveying the energy efficiency of domestic buildings along with recommendations for improving their efficiency. EPCs provide an energy efficiency rating (on an A-G scale) which is related to the running costs of a property.

The EPBD requires that all homes, commercial and public properties have an EPC when sold, built or rented, as well as when a building is converted into fewer or more units, or changes are made to heating or domestic hot water systems, or air conditioning or ventilation systems (exceptions include homes that will be used less than 4 months per year). DCLG is tasked with ensuring compliance with the EPBD

EPCs are based on a computational model which uses standardised assumptions and methods for estimated energy usage. Information on many variables is captured, including:

- The size of the building;
- Glazed area and orientation;
- Insulation levels;
- Construction type and materials;
- Heating, ventilation and air conditioning (HVAC) systems;
- Fuel sources and on-site energy production.

Accredited assessors must be used to produce an EPC (Domestic Energy Assessors for UK domestic properties). Although there are criticisms of the accuracy of the EPCs computational model (in the context of SWI, most commonly about assumptions of performance of 'breathable' masonry constructions), as well as the perceived lack of rigour with which assessments are sometimes made, EPCs provide a simple means of approximating and communicating typical performance and potential of possible improvements.

B.9 Building Regulations and controls of SWI retrofitting

SWI retrofit specification and workmanship are controlled in part by Building Regulations. In England and Wales, these are maintained under the UK Building Act 1984. Under this Act, the Welsh Government is given power to maintain its own regulations. Scotland and Northern Ireland have similar but distinct legislation. Powers in England and Wales to amend the scope of regulations have been provided by two further Acts of Parliament: the Sustainable and Secure Buildings Act 2004 and the Climate Change and Sustainable Energy Act 2006.

Secure and Sustainable Buildings Act 2004

The Secure and Sustainable Buildings Act 2004 (UK Parliament 2004) amends the Building Act 1984, and introduces new objectives to Building Regulations, which include:

- Furthering the conservation of fuel and power.
- Facilitating sustainable development.
- Furthering the protection or enhancement of the environment.
- The prevention of waste, undue consumption, misuse or contamination of water.

The Act also requires the DCLG to deliver a biannual report to Parliament on the anticipated effects of the Act's measures, including information on energy efficiency in buildings, climate change-related emissions levels, and the extent to which building materials are recycled or re-used in origin. The Act is particularly noteworthy as it initiated the focus on energy efficiency in UK building regulations.

Part L1b: Existing Buildings (Conservation of fuel and power)

Part L1b: Existing Buildings (Conservation of fuel and power) (HM Government 2013) establishes u-value trigger points for 'consequential improvement', as shown in Table 12 (overleaf).

Table 12: u-value trigger points for 'consequential improvement' in Building Regulations Part L1b

	A	B	C	D
	Threshold u-value triggering improvements to thermal elements (W/M^{2}k)	Requirement for thermal elements worse than column A (W/M^{2}k)	Standard u-value requirement for extensions (W/M2k)	Minimum acceptable u-value for extensions*** (W/M2k)
Cavity Wall	0.7	0.55*	0.3	0.7
Other wall	0.7	0.35	0.3	0.7

*walls not suitable for cavity wall insulation should be treated as 'other wall'
***where alternative approaches such as SAP assessment are used

Part L1b (HM Government 2013, p.19) stipulates that "Consequential improvements should only be carried out to the extent that they are technical, functionally and economically feasible". Regulations (HM Government 2013, p.9) provide exceptions for improvement requirements for "Historic and traditional buildings where special considerations may apply". Section 3.8 provides exceptions "where special considerations in making reasonable provision for the conservation of fuel or power may apply"; these include "Buildings of traditional construction with permeable fabric that both absorbs and readily allows the evaporation of moisture." Section 3.9 notes that:

> When undertaking work on or in connection with a building that falls within one of the classes listed above, the aim should be to improve energy efficiency as far as is reasonably practicable. The work should not prejudice the character of the host building or increase the risk of long-term deterioration of the building fabric or fittings.

The Regulation stipulates that in EWI projects, technical risk assessment must be made of increased wall thickness on adjoining buildings. It notes that in IWI, triggers are contingent on assessment of impact on internal floor area; a reduction of more than 5 per cent is considered unnecessary. It provides a range of other exceptions to the consequential improvement requirements.

Condensation and moisture risks are required to be assessed and mitigated in accordance with Part C of the regulations.

Requirements for workmanship and materials selection is limited, and is based largely on Regulation 7 (see following section). Part L1b requires that work should “be carried out with proper materials and in a workmanlike manner” (HM Government 2013, p.10).

Stipulations for building control are also included (HM Government 2013, p.11); these allow acceptance of:

> …the certification of the installation or maintenance of products, components, materials or structures under such [UK product certification schemes which certify compliance with the requirements of a recognised standard that it is appropriate to the purpose for which the material is to be used] schemes as evidence of compliance with the relevant standard.

No guidance for common sources of information in SWI is provided (no provision of training on SWI for building control officers has been found in research).

Finally, relevant regulations for new construction are contained in Part L1a (HM Government 2013a, p.17) (these do not apply to SWI retrofit. It notes:

> the building fabric should be constructed to a reasonable standard so that:

- The insulation is reasonably continuous over the whole building envelope; and
- The air permeability is within reasonable limits.

Regulation 7

Regulation 7 stipulates work must employ “adequate and proper materials” and be conducted in a “workmanlike manner” which (HM Government 2013b, pp.7–8):

> (i) are appropriate for the circumstances in which they are used,
>
> (ii) are adequately mixed or prepared, and
>
> (iii) are applied, used or fixed so as adequately to perform the functions for which they are designed; and
>
> (iv) in a workmanlike manner.

Section 2: Workmanship (HM Government 2013b, pp.7–8) suggests “ways of establishing the adequacy of workmanship” as follows:

- CE marked products
- Work in compliance with British Standards or other technical specifications (including BS 8000 series of standards on workmanship on building sites
- Independent certification schemes
- Covered by a management systems, such as one that complies with BS EN ISO 9000

- past experience, such as use in an existing building, may show that workmanship is appropriate for the function for which it is intended"
- Tests (required for sound insulation in regulation 41, air flow rate of mechanical ventilation in regulation 42, pressure testing in regulation 43)
- Regulation 45 of the Building Regulations 2010, regulation 8 of the Building Regulations 2010, and section 33 of the Building Act 1984, building control bodies have powers to make tests as the consider necessary to establish whether building work complies with the requirements of regulation 7
- Voluntary testing made by builders

Workmanship: other regulations and standards

Workmanship and building practice standards are controlled in the UK by a range of standards and codes which have evolved over the past fifty years. These include:

- BS EN ISO 9000 which covers systems and a series of standards
- BS 8000 Codes of practice and workmanship on building sites:
    - Excavation
    - Waterproofing
    - Carpentry and joinery
    - Roof tiling and claddings
    - Plasterboard and dry lining
    - Painting and decorating
    - Above ground drainage and sanitary fittings
    - Sealants
- European Regulation 305/201/EU-CPR (2013), governs conformity to the European Technical Assessment and CE marking of building products
- NBS (National Building Specification), provides data and standards for over 5,000 proprietary construction products and systems

Additionally, numerous independent bodies and third bodies provide certification of products and processes in the UK. One example of an independent body is the United Kingdom Accreditation Service (UKAS). Many manufacturers and system suppliers (e.g. those in the SWI supply chain) provide both certification of products and installation processes as well as training in specification and proper installation procedure.

Finally, workmanship is arbitrated in legal proceedings and courts. This relies on contractual frameworks between any of a range of parties including client, manufacturer, supplier, installer, specifier, and guarantor. Contractual documents typically categorise construction defects in four ways, which is reflected in the UK legal framework; these include: material defects or deficiencies, inadequate or unfitting design, inappropriate specification, faulty workmanship.

Across the domestic and non-domestic construction industry, energy performance standards are being increasingly demanding and post-construction testing (e.g. envelope permeability testing) is becoming required by building regulations. In this context, workmanship is more and more coming under close inspection and so workers and construction managers are becoming aware that they must work to workmanship thresholds

Appendix C -- Niche market and near-market insulants

Table 13 contains a list of known niche market and near-market insulation materials (Jelle 2011; Jelle et al. 2010; Petter et al. 2012; Baetens et al. 2010; Baetens et al. 2011. These are presented in categories and accompanied by notes or descriptions.

Table 13: Niche market and near-market insulants

Category	Insulant	Description	Notes	Vulnerabilities
Niche market, high performance	Argon or krypton-filled gas panels	Foil-coated plastic panels filled with low-conductivity gas	Potentially xenon could be used (lower conductivity than krypton or argon)	Perforation
	Supercritical dried silica gel (Aerogel)	Pelletised, available in board	Lightweight	
	Vacuum insulation panels (VIPs)	Typically film enveloped fumed silica, PET plastic or other material in a latticed structure formed in a rigid board and evacuated.	Waterproof, recycled glass (silica), load-bearing. 5-10 times lower conductivity compared to conventional materials. Overall thermal conductivity of less than 4 mW/(mK) as manufactured	Vulnerable to perforation and increasing conductivity over time

Category	Insulant	Description	Notes	Vulnerabilities
(Continued)	Foamglas	Rigid cellular glass block	Load-bearing, structural applications. Impermeable to moisture. Fire resistant.	
Other	Phase change materials	Latent heat storage materials commonly sold encapsulated and in board form	Not an insulant by conventional definition	Performance generally diminishes over time.
Near-market/innovation and research	Gas insulation materials	Generally homogeneous with closed cell structure, filled with low-conductivity gas	Low manufactured conductivity	Vulnerable to perforation and increasing conductivity over time
	Nano insulation materials	e.g. 'nanospheres' -- a foam made of nanoscale hollow spheres	Closed or open cell structure	
	Dynamic insulation materials (DIMs)	Can be controlled within a designed range	Experimental work is being conducted to control conductivity by three means: adjusting inner pore gas content or concentration, altering the emissivity of the pores, altering conductivity of the lattice matrix.	

Category	Insulant	Description	Notes	Vulnerabilities
(Continued)	Xerogel	Desiccated solid gel	Contains incredibly high ratio of surface area to weight. Same chemical reaction as Aerogel, but uses ambient drying not supercritical drying.	
Niche market, 'natural' material	Straw bale	Compressed straw bale	Low embodied energy. Required thickness generally requires structural works.	Generally not approved for structural load. Must be protected from prolonged contact with moisture.
	Cork board	Direct-fixed board	High transport distance to UK	
	Cementitious foam (magnesium oxide cement)	Blown lightweight cellular concrete	Fire and insect resistant. Magnesium oxide has potential to sequester substantial quantities of CO_2.	
	Cotton	Loose fill or batt	Post-consumer recycled formulation	Must be protected from prolonged contact with moisture.
	Sheep wool	Loose fill or batt	Non-toxic, mould-resistant, fireproof, CO_2 fixing	
	Wood fibre and cellulose	Loose fill or batt	Capable of significant reduction in air infiltration. Advantageous moisture buffering	

Appendix D -- Description of observations under COST action in coincident research

D.1 Reno2020

The host group and its partner organisations carry out performance-monitored whole-house energy retrofit of domestic buildings through the Reno2020 research programme and this includes full-envelope SWI. Site visits to two refurbished solid brick dwellings provided opportunity for inspection of SWI installation and discussion with researchers about successes and failures in SWI strategies.

D.2 Belgian Building Research Institute (BBRI)

The BBRI is an applied scientific research centre which serves the Belgium construction sector with technical support and research. A tour of its research facilities included a durability and physical testing laboratory, thermal resistance laboratory, and a recycled materials demonstration project; this was accompanied by presentations from and discussions with a number of staff researchers. Topics of discussion with staff included mechanisms of knowledge exchange with the construction industry.

D.3 Facility tour and meeting: Ecobati

Ecobati is the largest supplier of ecological building materials in Belgium and delivers training on installation of 'natural' insulation materials (as well as other construction materials). Discussion with the company director focused on insulation materials sold by the company and the training of insulation installers which the company conducts. Discussion highlighted the advantages (and disadvantages) of using ecological materials for insulation and the experiences reported by members of the Belgian installation industry.

D.4 Factory tour and meeting: Dolcea

Dolcea is Belgium's first cellulose insulation manufacturer and has recently opened a production facility near Namur. A tour of the facility included observation of the low-energy manufacturing process as well as a variety of laboratory equipment used to test thermal resistance, compaction and other physical properties of the insulation.

Discussion with the facility management provided an overview of the production of the insulation material and installation guidelines.

D.5 Factory tour and meeting: Knauf Insulation

Knauf Insulation is a major international manufacturer of insulation for buildings. A visit to one of their production facilities and offices was hosted by the Head of Building Science at Knauf. An extensive interview gave an overview of Knauf's research programme, which includes a variety of hygrothermal topics and the development of products and techniques to address related challenges.

D.6 Wallonia Construction Confederation

The Wallonia Construction Confederation (WCC) is a representative body for the Wallonia region's construction industry and it provides a variety of advice services to its members. Its remit includes developing and supporting training programmes for construction industry members, and providing consulting services on energy regulations and standards. A discussion at WCC offices in Brussels included two officers and focused on training programmes for construction workers and insulation installers in Wallonia.

D.7 Building Sector Education Institute, Luxembourg

The Building Sector Education Institute (BSEI) in Luxembourg is an industry levy-supported training and education organisation. A visit to their facility included meeting several members of senior administration and tour of their training facility. The BSEI is known for its vanguard status in construction industry skills training and education.

Appendix E -- EWI Quality Assurance Procedure System form from Phase 3 Company

To ensure anonymity, this document appears in text-only format with company logos removed.

PAGE 1 – Project title; property address; notes

PAGE 2 – 'Stage 1: introduction'

Yes/no/NA fields:

Initial survey carried out

a) Resident introduction carried out
b) Resident profile completed
c) Dilapidation survey completed
d) Resident disclaimer signed
e) Colour choice form completed
f) Gas survey completed

Survey carried out by

Notes

Name, date

PAGE 3 – 'Stage 2: Preparation'

Yes/no/NA fields:

Preparation works completed

a) Satellite dish repositioned
b) Aerial repositioned
c) Telephone cables repositioned
d) Lights etc. isolated
e) Gas flue checked/extended
f) Live vents identified and maintained
g) Plumbing alterations completed
h) Task sheets completed and attached

Notes

Name, date

PAGE 4 – 'Stage 3: Full depth beads and flashings'

Yes/no/NA fields:

Beading works completed

a) The requirement and the correct location of bellcast beads, stop beads, verge trims, undercill or overcill has been identified and agreed
b) The correct position for any part wall has been identified and agreed
c) The correct details have been agreed and followed for beading around apetures [sic], projections and obsticles [sic]
d) All beads and flashings have been installed correctly with neat mitre or abutting corners joints, joint pieces used as required and mechanically fixed at 300mm centres
e) Mastic has been applied as required to all high level flashings
f) All offcuts and debris removed
g) A visual inspection has been carried out and the beading accepted

Notes

Name, date

PAGE 5 – ' Stage 4: Installation of insulation boards'

Yes/no/NA fields:

Insulation works completed

a) A visual inspection has been carried out, all live vents are unobstructed and the insulation works are completed
b) Installed horizontally along the long edge with staggered joints minimum 200mm apart
c) Installed with tightly butted joints. Excessive gaps at insulation joints filled with expanding foam.
d) Insulation has interlocked brick bond joints at all corners.
e) Insulation board cut in 'L' shaped pieces around openings.
f) Correct mechanical fixing pattern used with washer plate flush to the insulation board surface.
g) Additional fixings installed at 300mm centres around all windows, doors and at building corners and at 600mm centres at the top and bottom of the system.
h) Any damaged insulation or fixings has[sic] been replaced or repaired.
i) All offcuts and debris removed.

Name, date

PAGE 6 – 'Stage 5: Fixing of surface beads and scrim coat

Yes/no/NA fields:

Scrim and bead works completed

a) A visual inspection has been carried out, all live vents are unobstructed and the scrimming works are completed
b) Angle beads are installed correctly with neat mitred or abutting corner joints.
c) Angle beads are plumb and in line and level with the openings and system edges
d) Bellcast and stop beads are in line and level and have been dubbed [sic] out as required.
e) Base coat is free of lumps and has been applied smoothly without excessive trowel marks
f) Render has been applied in correct thickness prior to embedding scrim reinforcing mesh.
g) Reinforcing mesh overlapped a minimum 100mm
h) Additional reinforcement patches 200mm x 600mm installed at all corner openings.
i) Drains clear of obstruction and blockages, all areas cleaned and free of offcuts and debris.

Name, date

PAGE 7 – 'Stage 6: Application of finish coat'

Yes/no/NA fields:

Finish work completed

a) A visual inspection has been carried out, all live vents are unobstructed and the finishing works are completed.
b) A mastic seal has been applied to all abutments to non similar [sic] materials eg. [sic] soffits and windows.
c) Finish coat has been applied to the correct thickness, is free of lumps and has been applied smoothly without excessive trowel marks.
d) The aggregate has been throw [sic] onto the rendered surface to give a coverage that is both uniform and dense.
e) All reveals and rendered returns have been completed and are both square and even with straight neat edges at abutments to non similar [sic] materials.
f) All beads, windows, window cills have been cleaned together with the removal of any protection in readyness [sic] for handover.

g) Drains clear of obstruction and blockages, all areas cleaned and free of offcuts and debris.
h) Temporary downpipes installed as required to avoid water damage.

Name, date

PAGE 8 – ‘Stage 7: re-instatement’

Yes/no/NA fields:

Reinstatements works completed

a) Satalitte [sic] dish repositioned
b) Aerial repositioned
c) Telephone cables repositioned
d) Lights etc. reconnected.
e) Gas flue checked/extended
f) Live vents identified and maintained
g) Plumbing alterations completed.
h) Task sheets completed and attached.

Name, date

PAGE 9 – ‘Declaration’

Fields:

System manufacturer

System reference

to the best of my knowledge work has been completed in accordance with the system manufacturers [sic] project specification and the installation progress stages deialed [sic] within.

Signed, date, print full name

Appendix F -- Training and Assessment Routes for Solid Wall Installers (EWI & IWI Routes), produced by Construction Industry Training Board.

Training and Assessment Routes For Solid Wall Installers (EWI & IWI Routes)

Route	Type of Trainee/Learner	Training & Assessment Requirements
1	**Experienced Operatives** Experienced Installer/Operative currently engaged in the installation of Solid Wall Insulation Systems (External or Internal Wall Insulation Systems).	• Customer service training • Green Deal knowledge training • Health & Safety training as described in PAS 2030 • NVQ registration for the qualification • Onsite assessment of the NVQ level 2
2	**Operatives who require occupationally specific training** Construction operative or craftsperson NOT previously involved in the Installation Solid Wall Insulation Systems (EWI/IWI). These candidates would be seen as Up-skillers who have worked in the construction industry in various roles and who require a minimum level of occupationally specific training in external or internal wall insulation systems. Operatives must be working on the installation of EWI and IWI systems so they can be assessed for the NVQ.	The basic requirements will include all of the above at Route 1: • Customer service training • Green Deal knowledge training • Health & Safety training as described in PAS 2030 • NVQ registration for the qualification • Onsite assessment of the NVQ level 2 Plus • Individual training needs must be assessed by the training provider • Occupationally specific training in the fixing and finishing of EWI & IWI systems. • The duration of occupational training required will be 4 days or less. • Knowledge of retrofit is a training requirement • The training required by each person will be assessed against the agreed industry standards and a training and assessment plan must be issued to the candidate.

Training and Assessment Routes For Solid Wall Installers (EWI & IWI Routes)

Route	Type of Trainee/Learner	Training & Assessment Requirements
3	**SUPs: New Entrant Adult Up-Skilling Operatives** This group will comprise of candidates who are 18+ years of age and have no previous experience of working on Solid Wall Insulation systems, but may have some transferrable skills obtained through other work within the construction industry. As such they are adult new entrants following a Specialist Up Skilling Programme (SUP). This route is managed by a National Specialist Team and training providers who wish to deliver this route must first be issued with a service level agreement by the National Specialist Team. Candidates following this route will be required to follow the EWI or IWI industry approved Training Modules.	Training required will include all of the above at Route 2 **Plus** A training programme determined by the number of off the job training days to be followed of either • 5 days • 6-9 days • 10+ days • The grants available will be relative to the number of off the job training days completed. • The total programme duration is one year
4	**SAP Specialist Apprenticeship Route** This programme is aimed at new entrants candidates who are aged between 16 to NO UPPER AGE LIMIT Delivered in partnership with the appropriate employer federation (i.e. INCA in the case of EWI) and/ or their nominated approved training provider. All training providers must have been issued with a service level agreement by the National Specialist Team before training can be delivered. ***Note Only the EWI Route is available for Solid Wall Insulation. The Internal Wall Insulation Route is not yet available and is under development.***	• Completion of 21 days of off the job training • Significant on the job training support is provided • The programme is completed over 2 years • Achievement of the NVQ level 2 • Completion of the SAP Apprenticeship Framework

Training and Assessment Routes For Solid Wall Installers (EWI & IWI Routes)

Route	Type of Trainee/Learner	Training & Assessment Requirements
5	**SASE Apprenticeship Route:** Skills Funding Agency (SFA) funded Apprenticeship Framework. • External Wall Insulation pathway • Internal Insulation pathway	A full apprenticeship framework is available and includes the following compulsory elements: • Employment Right and Responsibilities (ERR) • Personal Learning and Thinking Skills (PLTS) • Functional Skills • Completion of Diploma • Completion of NVQ

Appendix G -- "Plasterers Induction Programme 2013": the induction programme for EWI NVQ2 apprentices from Training College 2

Week 1

	Monday	Tuesday	Wednesday	Thursday	Friday
A.M.	Induction to company	EWI Health and Safety Awareness Training	Emergency first aid at work	CSCS Training and Assessment	Centre tour (open day for family). Introduction to company and Green Deal. CSCS reassessment.
P.M.	CITB Induction and enrolment	CSCS training	Emergency first aid at work	Asbestos awareness training	As above

Week 2

	Monday	Tuesday	Wednesday	Thursday	Friday
A.M.	Boarding (practical workshop)	Boarding (practical workshop)	Boarding (practical workshop)	Boarding (practical workshop)	Boarding (practical workshop)
P.M.	Boarding (practical workshop)	Boarding (practical workshop)	Boarding (practical workshop)	Boarding (practical workshop)	Boarding (practical workshop)

Appendix H -- Extracts from 'A Trainer Resource Manual for Insulation and Building Treatments'

These extracts show sections on guidance for selecting insulation materials and pre-installation remedial measures for pre-existing damp (ConstructionSkills 2012, pp.59–60; 67) (overleaf). Note that the guidance on damp walls (p. 67) does not recommend that damp walls are not suitable for SWI; rather it recommends that damp ought to be sealed within the wall before treatment.

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Appendix I -- 'Job knowledge questions' document: Phase 3 Company training material provided as revision material for NVQ2 mandatory assessments.

Summary: The document contains questions from the NVQ2 assessment and model answers. It is organised into 5 sections, reflecting the NVQ2 units:

- QCF 641: Conforming to General Health, Safety and Welfare in the Workplace (pp. 2-7)
- QCF 642: Conforming to Productive Working Practices in the Workplace (pp. 8-11)
- QCF 643: Moving, Handling and Storing Resources in the Workplace (pp. 12-19)
- QCF 448: installing External Wall Insulation in the Workplace (pp. 20-23)
- QCF 449: Applying Surface finishes to External Wall Insulation in the Workplace (pp. 24-26)

Extracts from each section are provided as an indication of the nature and scope of the document. Each section consists of questions taken from the NVQ2 assessment and model answers offered by Phase 3 Company training staff.

QCF 641: Conforming to General Health, Safety and Welfare in the Workplace

Question: State how the health and safety control equipment relevant to the work should be used in accordance with the given instructions.

Answer: Comply with health and Safety information in Site Inductions and Operational method Statements for Safe Systems of Work and wear all PPE as set out in site rules as well as any specific PPE required by Risk and COSHH Assessments.

QCF 642: Conforming to Productive Working Practices in the Workplace

Question: Describe how to maintain good working relationships, in relation to individuals.

Answer: Communicate verbally to ensure safe working relationships.

Question: Describe why it is important to work effectively with line management, colleagues and customers.

Answer: to complete work safely and on time with no disruption and to ensure correct materials are on site.

QCF 643: Moving, Handling and Storing Resources in the Workplace

Question: Describe how to obtain information relating to using and storing lifting aids and equipment.

Answer:

From Method Statements, Risk assessments, training courses and manufacturers [sic] information.

QCF 448: installing External Wall Insulation in the Workplace

Question: Describe the characteristics, quality, uses, sustainability, limitations and defects associated with the resources in relation to:

- Insulation materials, tracks, adhesives, sealants, mechanical fixing components, pre-formed trims, tracks and shims, beads, joints and cills
- Hand and/or powered tool and equipment

Answer: Rockwool phenolic EPS for external wall insulation can get damaged if stored incorrectly.

Tracks for base can bend.

Adhesives for bonding boards can get lumpy if damp.

Sealants can be damaged by extreme low temperature.

Preformed trims, tracks, shims, beads, joints and cills can get damaged through poor storage.

Question: Describe the needs of other occupations and how to effectively communicate within a team when installing external wall insulation and applying surface finishes to external wall insulation.

Answer: good communication is required between the team, management and other trades to ensure they have the tools, equipment and materials to complete the works in the time allocation to allow following trades to carry out their works.

QCF 449: Applying Surface finishes to External Wall Insulation in the Workplace

Question: Describe the characteristics, quality, uses, sustainability, limitations and defects associated with the resources in relation to:

- Mortars, dash finishes, proprietary pre-cast finishes, paints, beads, reinforcement, brick slips, render, sealants, fixings and fittings.
- Hand and/or powered tools and equipment.

Answer: mortars, powder for basecoats and topcoats can be affected by temperature or damp.

Dash for stone dashing can have a high degree of wastage.

Pre-cast finishes would include brick slips.

Paints are used as primers or on top of topcoats.

Beads are used for external angels and can get damaged.

Reinforcing mesh is bedded into the basecoat.

Sealants are for jointing boards at abutments.

Fixings for securing boards can be hammer or screw fixed.

Tools and equipment are used for applying base and topcoats, cutting and fixing boards and mixing powders.

Appendix J -- Excerpt from the Construction Skills Learning Exercise

This excerpt from the Construction Skills Learning Exercise (Psychometric Research & Development Ltd. n.d., pp.26–27) shows two of 40 questions in the publication and is typical of the difficulty and complexity of the exercises it contains (overleaf).

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