Deep retrofit approaches: managing risks to minimise the energy performance gap

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Abstract

Energy use in buildings remains a significant part of overall energy demand. Deep renovation projects, delivered at scale, remain a challenging task to achieve a lower carbon building stock. The complexity of building renovation is related to inherent characteristics of buildings, which require distinct project management techniques. While there are now more projects focusing on achieving operational performance, there is still very little research on the management of the renovation and retrofit process itself – this paper aims to contribute to that literature.

First, the policy context for renovation is briefly set out. Then five different approaches to building renovation are distinguished: whole house; fabric first; room-by-room, step-by-step, measure-by-measure. These categories provide the basis for analysis of the risk of there being a gap between designed and actual energy performance. In addition, ten stages of retrofit are set out, and three different types of risk at each stage distinguished: assessment, sequence, and communication.

Combining this typology of risks with the work stages and types of retrofit, the risks associated with renovation processes and technologies were estimated using evidence from cases studies of deep retrofits across the UK and EU. Risks are not restricted to just one retrofit type, nor are they found solely or predominantly in a small number of work stages. Risk management needs to be integrated into retrofit works, whichever approach is taken, at all stages and across the assessment, sequencing and communication aspects of the retrofit. Getting retrofit right will involve sophisticated strategies, and will require multiple innovations, which could include new management systems, new documents (e.g. Building Passports) and new professional practices, with implications for education and training. Minimising the energy performance gap will only be achieved with increased focus on this hitherto neglected aspect of deep retrofit.

Introduction

Buildings are responsible for approximately 40 % of energy use and 36 % of carbon dioxide emissions in the EU. Reducing energy use and carbon emissions from this sector is crucial to delivering EU and member states' commitments to meet carbon reduction goals. Because of the long lifetime of buildings, and the poor energy efficiency of much of the building stock, the main route to reducing energy use is through renovation of existing buildings. The scale of challenge, particularly taking into account the Paris Agreement aspiration of keeping global temperature rise below 1.5 °C (UNFCCC 2015), means that the focus is increasingly on 'deep' renovation – a process which results in the energy use and carbon emissions from buildings being very substantially reduced.

However, deep renovation projects are inherently complex, with many risks attached. Badly managed renovation can have very poor outcomes in terms of energy performance – the 'energy performance gap'- and in extreme cases can damage the buildings they were supposed to improve. In the UK, there have been examples of poor quality solid wall insulation projects, funded through a government-mandated schemes, resulting in very serious damp and mould problems, negatively affecting people's health and quality of life, as well as causing extensive property damage (De Selincourt 2018). This clearly highlights that if governments are promoting retrofit and deep retrofit, they need to put in place policies to manage the risks involved. Prior to doing this, there needs to be a clear understanding of the risks involved. This paper aims to characterise the process risks involved in deep retrofit and to suggest how these risks can be minimised, across a range of approaches to deep retrofit, and with reference to current policy developments. While this analysis is believed to be relevant across the EU, the evidence and examples used in this paper, come primarily from the UK.

The focus here is on project delivery: the design and installation of technology and new materials to an existing building in order to improve its energy performance. This is distinct from other topics which have been studied in relation to retrofit: the management of retrofit programmes and schemes (e.g. Rosenow and Galvin 2013, Rosenow and Eyre 2016, Galvin and Sunikka-Blank 2017, Greenwood, Congreve et al. 2017, Gillich, Sunikka-Blank et al. 2018); the configuration of consortia of partners to deliver retrofit projects (e.g.Mlecnik, Kondratenko et al. 2012, Mlecnik, Straub et al. 2019); studies of operational energy use (e.g. Gram-Hanssen 2008, Institute for Sustainability 2012, Gupta and Dantsiou 2013, Topouzi 2015, Gram-Hanssen and Georg 2018); consumer perspectives and priorities in home renovation projects (e.g. Gram-Hanssen 2013, WILSON, CHRYSSOCHOIDIS et al. 2013).

Managing and planning processes for retrofit vary considerably between projects not only because of the variety of sizes, measures and approaches but also because of the lack of standard requirements or guidance in the UK about who can carry out retrofit projects or how such projects should be managed. A retrofit project can be delivered by a full project team of project managers, designers, energy consultants, contractors etc. (Topouzi 2015); or by one or more contractors working together in one of several possible contracting arrangements (Maby and Owen 2015). In some cases, the property owner has played multiple roles – client, designer, project manager, energy consultant, labourer, specialist installer (Fawcett and Killip 2014).

Fawcett (2013), showed how retrofit can be delivered as an integrated 'whole home' project where multiple interventions are carried out together, but can also following a phased 'over time' model (step-by-step smaller projects with pauses in between). It has been estimated that existing market demand for 'over time' projects in the UK represent approximately €10 bn worth of opportunities each year for incorporating low-energy works at the same time as work is carried out for other (non-energy) reasons (Killip 2011, Owen, Mitchell et al. 2014). There is clearly a tension between design standards and market opportunity.

Professional guides all exist for project design, management and good practice in contracting between partners, but they are designed primarily for new construction projects, not work on existing buildings. Topouzi, Killip et al. (2017), argued that the very nature of retrofit projects adds additional sources of uncertainty and risk, which need to be managed, supporting the development of a revised retrofit-specific version of the Plan of Work published by the Royal Institution of British Architects (RIBA). This new plan of work importantly identifies three work stages in retrofit (the Appraisal, pre-construction and Repair/Maintenance stages), which do not have equivalents in new construction projects. This paper uses the retrofit-specific Plan of Work to analyse evaluation data from field trials of ambitious deep low-carbon retrofits in the UK in 2009–12 (the Retrofit for the Future programme).

The paper is structured as follows: first, the current European and UK policy for retrofit and deep retrofit is briefly described. Then we set out the different deep retrofit approaches that were trialled in the Retrofit for the Future (RfF) programme. This is followed by a description of the revisions to the RIBA Plan of Work, including the new work-stages for retrofit. The analysis involves interpretation of evaluation data in order to assign risk profiles (low, medium, high) for the process of retrofit, as evidenced in the RfF trials. The paper closes with a discussion and conclusions.

Policy context

In addition to the Paris Agreement signed by all EU Member states to restrict climate change to 1.5 C of warming, recently the EU has set carbon emissions reductions goals for all member states for short-term (2030), mid-term (2040) and long-term (2050) national energy efficiency renovation policies. With a view to the long-term goals for 80–95 reductions compared to 1990 at EU level, the aim for all individual members is set towards highly energy efficient and decarbonised building stocks, and transformation into nearly zero-energy buildings. In this, two key directives -the Energy Performance of Buildings Directive (recently recast) and the Energy Efficiency Directive- set the requirements for national policy strategies (European Commission 2018). Each member state has set a roadmap with measures to mobilise and increase investment in the renovation of their residential building stock, and stimulates cost-effective 'deep' renovations. Measurable progress indicators domestically established assess in each member state the national milestones and actions achieved towards EU renovation targets. Although at EU-level, requirements indicate the mechanisms for financial measures to energy efficiency links to: the quality of the renovation works; the performance of the equipment or material used for the renovation; the level of certification or qualification of the installer; an energy audit and transparency of the assessment method, national policies (European Commission 2018). Implementation varies between member states.

In the UK for instance, the tools to support building owners' decision-making in favour of deep renovation are few and far between. Although not explicitly focused on deep renovation, concerns about ensuring the quality of retrofit in the UK's renovation strategy have been recognised. In an independent review of the Government's housing renovation strategy, quality risks arose as one of several issues related to implementation of retrofit schemes for mobilise retrofit investment (Bonfield 2016). In response, a new retrofit standard called PAS2035, currently in development, addresses technical and retrofit process issues related to the supply chain, product efficiency, installation quality and skills. In theory, this standard will cover the full range of renovation and deep renovation approaches and will be mandatory in renovations funded via the government-mandated Energy Company Obligation scheme.

A relatively new idea, 'Building renovation passports' is gaining support in several European countries, and is mentioned as a possible supporting policy for long-term renovation strategies in the revisions to the Energy Performance of Building Directive (Fabbri, de Groote et al. 2016, EuroACE 2018, European Commission 2018). This passport is a document (paper or electronic), which outlines a long-term (up to 20 year) step-by-step renovation roadmap for specific buildings based on a high quality on-site audit. The idea is that it is prepared in consultation with the building owner and ensures that the full energy efficiency potential of the building is achieved. The idea has been under development in Germany for some years and is currently being piloted in Germany, France and Flanders (Belgium) (Fabbri 2017).

Deep retrofit approaches

The primary evidence for this paper comes from monitoring and evaluation of field trials of ambitious 'deep' retrofit in the UK in 2009–2013 under the Retrofit for the Future (RfF) programme. In total, 119 low-rise houses underwent ambitious retrofit projects, where the aim was to test the viability of energy performance standards of 17 $kgCO_2/m^2$/year (115 kWh/m^2/year primary energy consumption), which is roughly equivalent to an 80 % reduction in emissions from an average UK house. Up to £150,000 (approximately 180,000 euros at 2012 exchange rates) was available per house, including technical monitoring. The RfF programme is still the only UK field trial of any significant scale to test such ambitious energy renovation standards for existing homes.

The published official evaluation for RfF comprises a short summary report and a database of projects, but this dataset is supplemented by detailed qualitative and quantitative analysis of a sub-set of 26 of the RfF projects (Topouzi 2015).

The RfF projects reflected different broad approaches, ranging from fully integrated 'whole house' projects, where multiple interventions were carried out in one go – through to less disruptive and costly approaches delivered in phases, and which can be categorised as 'over time' or staged. The RfF projects included three different 'one off' approaches – 'whole house' 'fabric-first' and 'room-by-room'. Other approaches to retrofit can be characterized as 'step-by-step' and 'measure-by-measure'. These are described in Table 1, which also illustrates the different variants between different approaches as identified in the literature.

The selection of retrofit approach often depends on clients' financial and lifestyle constraints. In the UK, one-off interventions combining 'whole-house', 'room-by-room' and 'fabric-first' refurbishment approaches were tested in large pilot deep retrofit projects in social housing (e.g. Retrofit for the Future (TSB (2014)). Owner-occupied housing largely involves over-time 'step-by-step' and 'measure-by-measure' retrofit interventions, which can be driven by existing policy and regulation and do not usually involve thorough medium to long-term low-carbon improvement plans (Fawcett, 2014).

The retrofit Plan of Work

In new buildings, the construction process involves certain established normative practices in planning and management that all projects need to follow, independent of their size, targets or energy efficiency scope. The critical problem in retrofits is the inherent complexity in project management, compared to new build. The whole process does not start with an empty site and is not delineated by well-established work stages. Retrofit works can start at any stage of an established process (e.g. in the UK Plan of Work RIBA 2013). This can either be planned starting with an assessment, design brief and followed by all design-construction-handover stages; or can be triggered by a single replacement starting just at construction stage missing out the impact this intervention has on the whole building performance (Figure 1). Within a retrofit process the causes of underperformance tend to arise and re-occur within multiple stages. In the UK established project work frameworks for project planning of existing and new buildings, like the RIBA and the Soft Landings framework (RIBA 2013, BSRIA

Table 1. Categorization of five approaches to retrofit.

Retrofit approach	Description	One off	Over time
Whole house	Sees the building as a system of different elements/interfaces and users that interact with each other. The retrofit is not a replacement of individual measures and systems that are independent of each other and from users' practices and lifestyle.	X	X
Fabric first	Prioritises interventions that maximise the performance of components and materials of the building fabric (e.g. insulation and air-tightness measures), before considering the use of other heating and ventilation building services.	X	X
Room-by-room	Undertakes interventions for a room at a time, addressing upgrading guidance of energy efficiency measures like insulation or glazing etc. alongside occupants' occupancy and lifestyle priorities.	X	X
Step-by-step	Undertakes specific improvements with a sequential order over years or decades that depend on 'trigger points' such as the financial investment and occupant's lifestyle in terms of acceptance of disruption or lifestyle changes. This requires a considered low-carbon improvement plan to avoid missed opportunities and lock-in interventions.		X
Measure-by-measure	Undertakes improvements as arise from an isolated measure or system failure or life span replacement. This piecemeal approach does not consider the interaction between systems.		X

2015), are mainly designed with new buildings in mind and not wholly aligned with the tasks, objectives and issues encountered in a retrofit process. The process of construction planning and management in retrofits is distinct from a new build as it involves different retrofit approaches that can have different time length planning (one-off/ over-time), managed by different people (e.g. homeowner at the role of project manager), and do not necessarily follow a formal sequence of stages. Existing buildings are challenging as they are an assemblage of materials and systems, a series of past interventions that occurred at different times, by different people, complying with different regulations and standards and users' needs. Previous work (Topouzi, Killip et al. 2017, Topouzi, Killip et al. 2017) developed a retrofit-specific plan of work process with clear, sequential stages.

Figure 1, shows the amended version of the RIBA Plan of Work (RIBA 2013), with the three additional key stages identified; in which process risk arise (Stage 0: Appraisal, Stage 5: Pre-Construction and Stage 9: Repair/maintenance). Within the early stages (Stage 0–Stage 4) of retrofit planning, important retrofit decisions are made that determine the type (degree of ambition in terms of energy saving), approach (e.g. whole-house, Fabric-first, Step-by-step etc.) and timing (one-off or over-time) of the work. In a whole-house approach the sequence of works is planned following order of stages starting at Stage 0. For the planning of a retrofit process, Appraisal (Stage 0) is a key stage as renovation-specific baseline issues and constraints are identified and formally assessed to inform follow up design choices. In the Fabric-first, Step-by-step, Room-by-room and Measure-by-measure approaches the work plan can bypass intermediate stages moving straight on to construction. For these cases the additional Stage 5, takes a similar approach to Stage 0 in which the existing condition (building envelope, systems and use) of the whole building is systematically assessed before works start. It also means that in cases where Preparation and Design stages were carried out, there is an opportunity to check for problems that are apparent only when construction work starts and cannot be identified by the diagnostic tests at Stage 0.

At the other end of the cycle, the, Post-construction /In-use stage (Stage 8), is vital in a retrofit process to ensure the quality of installation and actual operation. With this in mind, the additional Stage 9 places emphasis on the whole retrofit cycle in which the building improvement is an ongoing process that involves repair and maintenance and does not end at the delivery but will continue to alter building performance and shape the baseline conditions for further cycles of renovation planning and management.

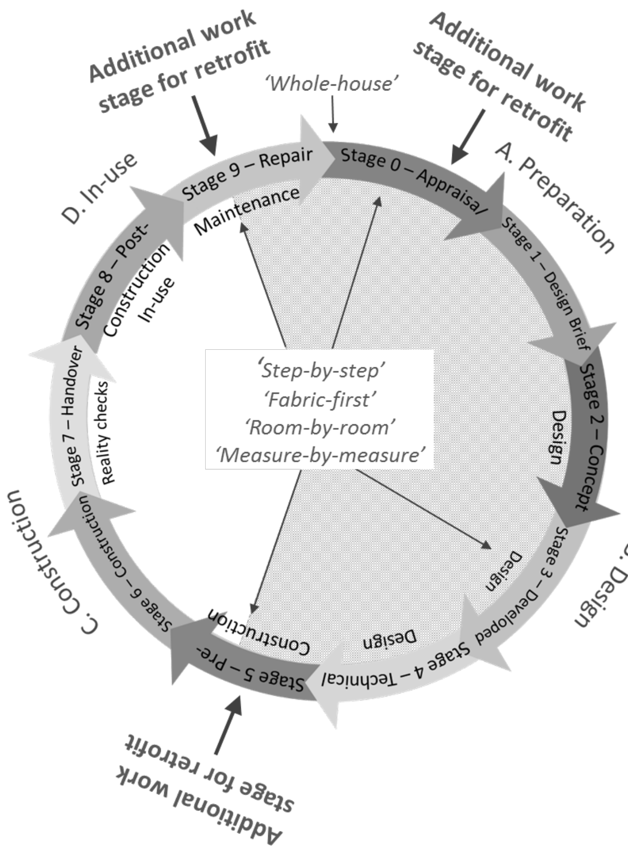

Figure 1. Renovation-specific plan of work and the start point for works of different retrofit approaches. Developed from Topouzi et al. 2017b.

Methodology

Our analysis used evidence from an extensive empirical database of deep retrofit projects in the UK, combined with outputs from a previous systematic analysis of 26 cases (Topouzi 2015) (see Table 2), to identify factors (activities) that affect time (one-off/ over-time), planning (retrofit stages) and approach type (Whole-house, Fabric-first etc.) of a retrofit project. First the primary data was crosschecked and matched against other published data and 'grey' literature (secondary data sources) to expand understanding of key factors and observed effects (e.g. incorrect package of decisions and installation actions) and associated causes (e.g. choice of diagnostic techniques) within retrofit work stages. The retrofit-specific work plan (Figure 1) was then used as a guide to identify and map which causes and effects in a retrofit process are most acute. A chain of relationships of causes/effects across work stages was analysed pointing to the trail of dominoes responsible for the performance gap (e.g. a cause that brings about a related effect, that in turn this effect becomes a cause for the next effect, and that all causes lead to the final effect). The cause of those effects we have termed as 'risks'. The frequency and impact of these causes gave the themes for key risks categories, which then distilled into a final set of three (Figure 2[1]).

Using a three point narrative/numerical rating scale (Low/ Unlikely – 1; Medium – 2; High/Likely – 3), the set of three key process risk types assessed and mapped to the retrofit approaches. The criteria used for risk rating considered as *Medium* the cases for instance in which despite all assessment techniques carried out the lack of specific skills diminished their input quality; while *High/Likely* were rated the cases in which these activities were completely omitted.

1. The full list of references consulted can be supplied by the authors.

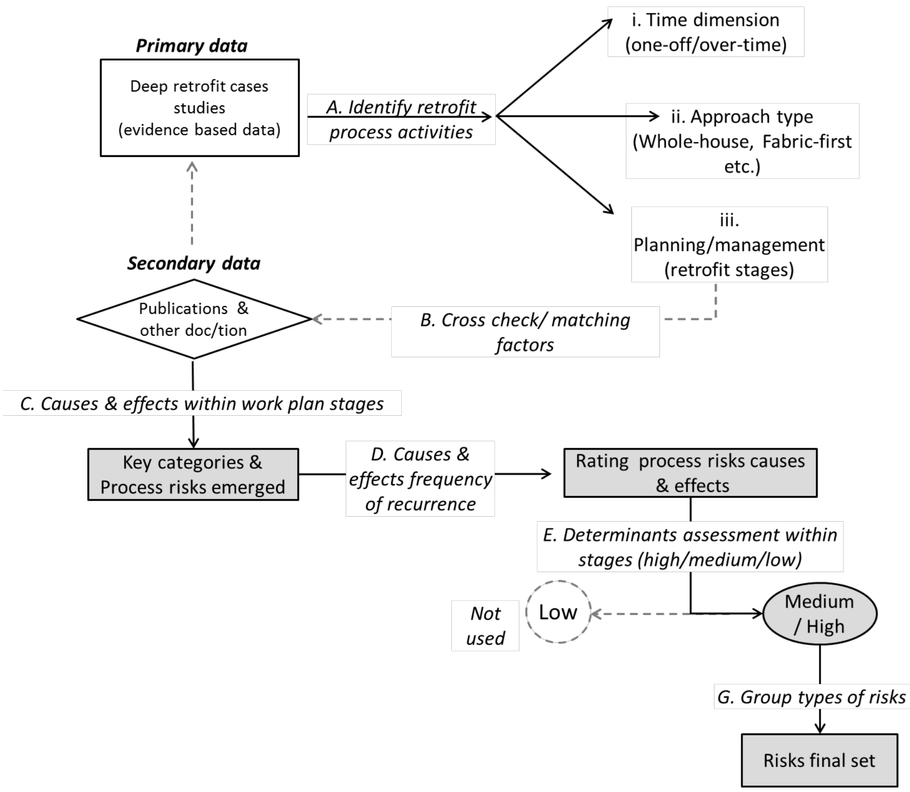

Figure 2. The approach used for the analysis of risks in multiple data sources.

Table 2. Example of the type of data used in the analysis of retrofit process risks.

Type	Description	Source
Primary Data set: **Evidence based data**	Retrofit for the Future (UK innovation project): large scale demonstration project of low carbon deep refits of low-rise social housing in the UK, (used dataset: Building information, semi-structured interviews, Post Occupancy Evaluation, projects planning documentation, in-situ metering/spot checks, 2 years physical and energy data, Post-construction reviews)	Retrofit for the Future demonstration project (2009–2013), Occupants' interaction with low-carbon retrofitted homes and its impact on energy use (Topouzi 2015).
Secondary data: Reports & publications	Online data sources on retrofit case studies; publications and reports on buildings retrofit approaches, planning and management, regulation and standards in the UK and EU. E.g. evidence from Superhomes homeowners on deep retrofits approaches and planning and coordination; retrofit approaches and Building Renovation passport examples.	Superhomes database (Superhomes 2013); EVALOC project (Gupta, Eyre et al. 2015); Retrofit insights: perspectives for an emerging industry. (Institute for Sustainability 2012); Occupant-centred retrofit: engagement and communication. (Institute for Sustainability 2012); Retrofit strategies (Institute for Sustainability 2012); Residential retrofit: 20 case studies (Baeli 2013), etc.

Results

The analysis presented here discusses the causes of risks in the management and planning of a retrofit process. Three key risks emerged: Assessment risks; Sequence risks; and Communication risks. Table 3 illustrates the types of risks that emerge in different retrofit approaches and work plan stages and contribute to the performance gap between design intent and actual performance.

Assessment risks: are related to the type of diagnostic techniques used to understand the building performance, the skills of people undertaking assessment and the time when assessments are carried out. In the 'whole-house' approach, this type of risk is relatively low compared to the other retrofit approaches; when retrofit is planned as a one-off intervention the evaluation of the building condition is integrated into the overall planning at early and later work stages. However, in projects carried out 'over-time', risks appear when diagnostic technique type or timing have not been part of project planning and budget. For example when a major intervention like cavity wall insulation is followed by window replacement, or external wall insulation in a different part of the building, the different measures can interact and require construction details (BSI 2017) that include thermal insulation detailing around corners, junctions, edges. Diagnostic tests like thermal imaging and a test of the air permeability of the building envelope to identify key leakage locations need to be repeated to assess the building envelope performance 'as-a-whole'. The degree of assessment risk in a project using a whole-house approach often arises because of the choice of an inadequate diagnostic techniques or a lack of skills in the people carrying out the assessment process. For example, Energy Performance Certificates (EPC) do not accurately reflect the real condition of the building fabric or miss out user's special lifestyle requirements that are needed to inform the design brief intervention choices (e.g. MVHR installation vs occupant's smoking habits and windows opening practices).

When the 'fabric-first' approach is used, assessment risks are increased in specific stages of preparation, design and in-use especially when works are carried out 'over time' and technical and in-use problems may not be recorded accurately, or at all. This means that there is incomplete data to inform future interventions of combined systems that would need to perform as a whole (e.g. installation of MVHR or low carbon heating system with under floor heating can negatively impact upon loft and floor insulation and overall draught-proofing and airtightness).

Generally, assessment risks are higher in room-by-room, step-by-step and measure-by-measure approaches because these involve individual measures that are not planned with the whole building performance in mind. Diagnostic techniques that could shape design decisions are not repeated when retrofit measures are implemented in stages over-time. In these approaches the techniques, assessment tools and diagnostic or problem solving skills of the team can vary significantly at different stages of a long-term retrofit project. The risk of selecting an incorrect package of measures, with installation decisions driven by the installer's current knowledge has both a short term effect in the package of measure not achieving the desired energy performance. These decisions also produce a "lock-in" effect constraining future interventions (e.g. the choice of heating system needs to be reflected in later decisions on radiator sizing and insulation).

Repair/Maintenance is an important stage of high risk across all approaches. Regardless of the scale or duration of the retrofit intervention, there is a culture in the construction sector that project management ends at the delivery stage (Bordass and Leaman 2013). Thus building assessment procedures are often overlooked entirely and final performance is not fed back into the project team for future learning (which would reduce future risks to energy performance on other projects).

Sequence risks: these are related to the choice of managing the order of retrofit works in long and short term planning. Even in the case of one-off whole-house approach, short term planning actions can be carried out in the 'wrong' order due to insufficient management. For example, structural damage can occur to thermally highly insulated roofs when photovoltaic panels are installed at later stage, if the installers do not take into account the insulation present. This can result in reducing overall building fabric performance. In the other approaches, unplanned interventions, perhaps to solve unforeseen problems, can compromise building performance. For example, holes drilled in wall insulation to allow re-wiring can reduce airtightness and decrease thermal performance. In an optimal sequence, re-wiring would be carried out before wall insulation was installed.

Communication risks: these are related to the communication methods (type, level/purpose, timing) that are used by different actors/roles involved in a retrofit process. In a whole-house approach poor communication between designers, users and installers at design and in-use stage can lead to inappropriate choices of technology, installation failures or on-site problem solving that is disconnected from other building components, design and usability principles. It can also leave residents unable effectively use the equipment in their homes (In use phase). A typical example being handover information on smart heating controls and MVHR system provided by the installers that is too technical, with no demonstration and explanation of combined systems principles. In room-by-room or measure-by-measure interventions the risk in communication is that roles and people involved vary over time, the interaction between different actors is limited or non-existent, and therefore information for systems that interact not provided.

Communication risks include two important subcategories of risks that are relevant especially in over-time approaches. The first has to do with the assigned responsibilities and the coordination of actors, which inherently involves fragmentation of roles affecting decision-making and construction project planning and management. The practice of sub-contracting measures and systems over time means that responsibility for overall performance does not sit with any individual. For example, where walls are insulated at one time, and high specification windows installed at another, neither the insulation installer or the windows specialist specifier might take responsibility for considering the effect of cold bridges between elements, leading to underperformance of the combination. Building users do not know who has responsibility for aftercare support for technical and operational problems of measures installed over-time.

Secondly, the opportunity for learning from the whole project is lost because of its fragmentation over time. Findings from reality checks, diagnostic tests and monitoring/reported unsolved installation and operational failures are not informing on-going design or maintenance decisions, with construction teams missing learning loops from previous experience.

Table 3 shows that the total combined risk score of these three types of risks across stages is lower in one-off interventions compared to over-time interventions. However, the large scale rollout of the one-off 'whole house' approach (EST 2009, TSB 2013, TSB 2014) is unrealistic for many private homeowners because of the practical aspects of disruption and/or the unaffordability of doing everything in a single investment (Energy Saving Trust 2010, Energy Saving Trust 2011). The evidence showed that it was common for this stage of renovation to lead a substantial performance gap, compared with design intent.

Table 3. Types of risks of a retrofit process and the likelihood of risks within different work plan stages.

Time		Over time only						One-off/ Over-time								
Retrofit approach		Measure-by-measure			Step-by-step			Room-by-room			Fabric-first			Whole-house		
Risk types*		C	S	A	C	S	A	C	S	A	C	S	A	C	S	A
Retrofit work plan stages	Preparation															
0 Appraisal	Preparation															
1 Design brief	Preparation															
2 Concept design	Design															
3 Developed design	Design															
4 Technical design	Design															
5 Pre-construction	Construction															
6 construction	Construction															
7Handover/Reality checks	Construction															
8 Post-construction in-use	In-use															
9 Repair / Maintenance	In-use															
Score & total combined risk across all stages		29	30	30	26	27	28	28	30	30	26	27	25	19	21	16
		89/90			81/90			88/90			78/90			56/90		

* Types of risks: Assessment (A), Sequence risks (S), Communication (C)

** Risk score: High / Likely – 3; Medium - 2; Low / Unlikely - 1

Discussion

Table 3 suggests that process risks of retrofit are always present, indicating that some form of risk management is needed in all cases. Risks are not restricted to just one type, nor are they found solely or predominantly in a small number of work stages. The implication of this is that risk management needs to be integrated into retrofit works, whichever approach is taken, at all stages and across the assessment, sequencing and communication aspects of the retrofit. Even the least risky approach, the whole house approach, involves significant risk.

It is striking that the process risks are significantly greater for all approaches other than the 'whole house' approach. The reasons for this are not always clear from the evidence especially for the over-time only approaches. However, some speculative explanations can be put forward for debate. Firstly, the integration of all the work into one project is consistent with having continuity of personnel. Not all the consultants, designers and contractors will remain throughout every project, but it seems reasonable to expect at least some continuity of aftercare support. We suggest that continuity of personnel is important for several reasons. Firstly, it provides institutional memory, so that even if documentation is incomplete or unclear, people can remember the decision-making process to fill in some of the gaps. Secondly, project teams inevitably develop a group dynamic, and individuals learn to expect certain responses (good, bad or neutral) from other team-members. The expectation that colleague X will (or will not) do a good job on a given task can translate into informal strategies for supervision or monitoring – paying closer attention where problems can be expected, but paying less attention when a colleague has consistently given excellent performance previously. And, thirdly, the unity of a single project means that all members of the team are working towards a common goal. They may perform their individual tasks more or less diligently, but the objective of the project needs to be a building's performance as a whole.

In contrast, we suggest that the 'over time' approaches are more likely to lack institutional memory; to experience greater change in the team dynamic; and to be more prone to situations where the original goals may get lost, subverted, forgotten or mis-remembered. Where there is a time delay between phases of a retrofit, it seems legitimate to ask whether and how these risks can be mitigated.

The concept of a Building Renovation Passport is relevant here, as it is intended to provide a form of documentary continuity in situations where there is no continuity of personnel or project objectives. The passport idea is worthy of further development and investigation, but we argue that it can only be successful if each document is kept up-to-date and accurate, and if it is used effectively in the planning, design and implementation of later retrofit interventions. The passport may prove to be a useful tool, but attention needs to be paid to making sure that it is used, understood and accepted by those who work on retrofit projects.

In addition, the quality management processes currently being developed in the UK's PAS2035 standard should be able to help reduce risks by identifying the qualification and skills needed at different project stages. The quality of management and project delivery is crucially important in retrofit.

Table 3 is a complex output of research – for each retrofit approach thirty different estimates of risk (by stage and by risk type) had to be evidenced. Particularly given that most components were judged as high risk – it is worthwhile differentiating risk to this degree? We believe that it is – for example, the assessment for the whole home approach shows where further efforts to reduce risk should be concentrated. Nevertheless, in future work it would be worth exploring the value of this approach with addition deep retrofit case studies in the UK and EU-wide (e.g. Energiesprong, cases using Building Renovation Passports).

Using a lens of potential risk analysis to examine retrofit projects allows us to propose future research to identify risk mitigation strategies. Initial ideas might be that retrofit co-ordination could mitigate the risks associated with communication and data/knowledge sharing for over time approaches. Documentation, such as the Building Passport, might provide a way of responding flexibly to new technologies/measures, lifestyle changes or policy strategies and incentives. A mitigation strategy for assessment risks might be to carry out repeated assessments in the key stages where there is a window of opportunity to fix installation issues and negatives impact of one measure upon another without building on the top of an existing problem or ignoring it. All of these ideas, and more, can be investigated in future research.

Conclusions

We have proposed a structured way of identifying, categorising and understanding risks that lead to energy retrofit objectives not being achieved in practice. The profile of these risks varies throughout a project life cycle and we have mapped these onto the RIBA work plan. In addition, our analysis recognises that projects altering existing buildings have distinctive characteristics specifically in terms the pre-existing condition of the building. We also identify five different retrofit approaches, which might be carried out "one off" or "over time". Clarity about the approach being taken helps a project team to be aware of the relevant risk profile of works and the potential impact on energy performance. Relevant mitigation strategies can then be identified and integrated into construction project management to help to reduce, and potentially eliminate, the energy performance gap.

The complexity and variety of retrofit projects needs to be given much greater priority in policy and industry debates about the future of retrofit. These projects carry significant risks, which are distributed among all work stages, not restricted to only a sub-set. Getting retrofit right will involve sophisticated risk management strategies, which is likely to involve multiple innovations: new documents (e.g. Building Passports), new practices (with implications for education and training). It will also involve further research: there is very little data describing the planning and management processes of retrofit projects, and the impact of planning and management decisions and behaviours on the energy performance of a building.

Stimulated by the title of the panel in which our paper is presented, we suggest that 'Making building policies great again' will need a profound change of culture in the ways retrofit works are planned and building works are documented and managed. Fortunately, new tools are being developed to help with this, but much more focus is needed on this hitherto neglected aspect of deep retrofit.

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Endnotes

Although the term 'deep' renovation/refurbishment/retrofit, is commonly used in the grey literature and buildings' energy efficiency Directives, there is no EU-wide legal definition of the term 'deep' (Economidou 2019). The GBPN's review of global use of deep' renovation pinpoints that there is a regional variation in the term definition. The term is used to describe deep improvement of the building envelope focussing on heating, ventilating and hot water and use of low carbon technologies aiming to significant decrease of the energy consumption. For example in Europe, 'deep" renovation implies a minimum of 75 % energy savings, whereas in the U.S. it means improvements of 30 %–50 %, while there are no common definitions in India and China (Shnapp, Sitjà et al. 2013). The deep retrofit case studies explored in this paper are in line with the Retrofit for the Future targets and as the term is defined in Topouzi (2015, pg. 11571158).

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