

Retrofit at Scale: Labour Intensive Approach and Capital Intensive Approaches for Housing Retrofit in the UK

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Abstract—To achieve net-zero emissions by 2050, decarbonising building operations by energy retrofitting has become a crucial priority. The UK’s building stock is ageing and the country is in the early stages of retrofitting. The scale of the work makes retrofitting a multi-billion-pound industry. Two primary approaches are emerging: the labour-intensive approach, relying on people and the capital-intensive approach, relying on capital and technology. This study employs a ten-question framework to explore the suitability of each approach. Findings highlight the diverse challenges in the UK energy retrofit industry. This study posits a hypothesis favouring a labour-intensive approach for energy retrofit in the UK. It does not exclude capital but advocates for leveraging existing resources to enhance skills rather than replacing them. Capital-intensive approaches are recommended as a top-up approach. The study’s value lies in its potential to inform policy on optimising investments in energy retrofit to meet net-zero targets, considering socio-technical factors.

Index Terms -- Capital-intensive, Energy retrofit, Labour-intensive, Retrofit at scale, United Kingdom.

I. INTRODUCTION

The United Kingdom has 30.1 million housing stock [1]. Further, the housing stock in the UK is considered to be the oldest and worst-performing in Europe [2, 3]. According to the recent statistics, the housing stock in the UK contributes 19.76% to the total UK carbon emissions [4]. Nearly 5.6 million households are in fuel poverty [5] and one in every five houses in the UK is considered to be below the standard quality of living [6]. Housing is a social determinant of health and well-being. Considering this situation, there is a dire need to upgrade the housing stock of the UK by retrofitting it to a satisfactory energy efficiency level. Considering the sustainability goals, it can be argued that almost all the houses will need some level of retrofit to reach 2050 targets for a decarbonised, comfortable and healthy residential stock [7]. Heat pump installation is a key requirement to a decarbonised housing stock as an electrified heating system can be easily decarbonised with a decarbonised electricity supply [8].

Considering the number of registered heat pump installations with MCS so far (<200,000), the UK can be considered at the beginning of retrofitting the housing stock [9].

Considering the approaches for retrofit at scale, the scope of the problem can be summarised as follows. There are 30.1 million houses to be retrofitted before 2050, to a level where there are no more carbon emissions, and residents pay lower energy bills while they are enjoying better health and comfort with their houses. Considering the existing case studies and the availability of certification schemes such as Passivhaus [10] or Energiesprong [11], the technology can be considered sufficient to do this. The retrofit industry is considered to be worth £250 billion to achieve the minimum level of energy efficiency to reach Net Zero 2050 goals [12]. There are contradictory arguments over the required minimum energy efficiency level expected from the residential stock [13]. If higher levels of energy efficiency are required, the retrofit industry value can further increase. The current labour government has allocated £13.2 billion for five years for energy efficiency measures for homes [14]. Supply chain or skills are also required to deliver the retrofit at scale. Although there are doubts about the availability, these can be expected to improve through a pull from demand for retrofit.

The housing retrofit industry is a billion-pound industry and the UK is in the early stages of retrofitting millions of houses. But, do we have a strategy? Is this strategy based on human skills or capital?

This literature review is expected to review these two approaches to retrofit the UK housing stock at scale. The study evaluated the UK policy strategies for retrofitting at scale and retrofit industry behaviour to understand the application and potential of labour-intensive and capital-intensive approaches. The ten-question method was followed. Concerning [15], the ten-question method helps to explore generic topics from a different point of view to stimulate discussion in academia as well as the industry. The ten questions were brainstormed by looking at the

problem from a broader perspective, inquiring into the details and closing the problem with recommendations.

II. TEN QUESTIONS

1. What are the objectives of housing retrofit in the UK?

The objectives of retrofit can be considered according to the type of retrofit client. In a housing retrofit project, the owner-occupier, the social or private landlord can be considered as the client [16]. The first client type is the owner-occupiers. They represent around 63.1% of the total housing stock. The other two segments are private rented and socially rented. They represent 19.1% and 17.7% of the housing stock respectively [3]. In general, reduction of energy bills, improved health & comfort, increased property value, durability, and aesthetics are some of the objectives of a client [7, 17, 18]. However, a split of interest can be observed between the occupants and landlords in the case of socially and private rented properties. Housing retrofit is also a national problem considering the UK government’s legal obligation to achieve net zero by 2050 and the duty to improve the health, comfort and prosperity of the residents [19]. Reducing carbon emissions from the housing stock, reducing fuel poverty and improving the health and comfort related to the housing stock are generally considered to be highly important topics related to retrofitting houses [8, 20, 21].

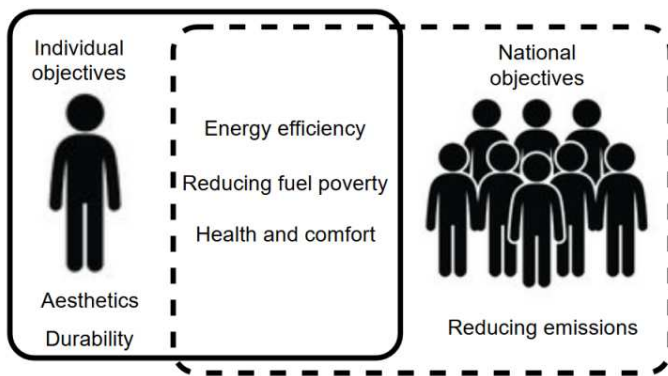


Figure 1. Objectives of retrofit

Figure 1 shows the objectives of housing retrofit according to individual and national requirements. The common objectives of the retrofit can be presented as improving the sustainability of the housing stock by focusing on energy efficiency, fuel poverty, better health and comfort of the residents. These objectives are valued both individually and collectively. Aesthetics, durability and property value are the individually valued objectives while emission reduction is mainly a national objective.

2. What are the core characteristics of a labour-intensive approach?

The labour-intensive approaches rely on human skills over technology. In some industries, human skills are difficult to replace due to the nature of the industry and the requirements of

the clients [22]. For example, the healthcare industry, design and creative industries, decision-making or hospitality industries will need the “human touch” for their operations. Activities in these industries are difficult to replace with technology with the same creativity level. The technology can be highly useful to improve operational efficiency. In general, the construction industry (mainly subcontracting) can be considered a labour-intensive industry [23]. Although several functions are being replaced with machines and some constructions are done in factories under offsite construction approaches, still the industry uses manual labour to a higher level. Further, the construction industry is one of the slowest industries to adopt technology and move out of labour-intensive practices [24].

3. What are the core characteristics of a capital-intensive approach?

In contrast, capital-intensive approaches focus on capital, technology and machinery to improve efficiency, productivity and performance. Manufacturing, logistics and some service industries mainly rely on capital-intensive approaches. These approaches highly focus on mass-scale operations to achieve economies of scale [25]. Due to the cost reductions and efficiency improvements, they can keep better profit margins while providing products and services cheaper. Automation is a key aspect of capital-intensive approaches [26]. Further, these approaches are involved with a significant early capital investment with the expectation of reducing costs during the operation.

The idea of capital-intensive approaches has gained insights from the manufacturing industry. These approaches are observed to have adopted the best practices of manufacturing to improve productivity and efficiency in construction. Notably, lean practices were originated in manufacturing, but are now being adopted in construction [27]. Design For Manufacturing and Assembly (DFMA) is an important concept in lean manufacturing. Lean supply chain management methods can be used to improve efficiency in the context of DFMA [28]. Modern methods of construction (MMC) use modular construction techniques to improve the construction process [29]. Prefabrication and offsite construction can also be considered under MMC. The methods use factory manufacturing of building components to achieve economies of scale [30]. These techniques are vehemently used in the construction industry under capital-intensive approaches.

4. How the retrofit industry in the UK has adopted these approaches in the past?

While most of the manufacturing sector has achieved significant cost savings and efficiencies due to automation [31], the construction industry is still using the same old techniques and tools most of the time [24, 27]. The offsite construction techniques and prefabricated construction components are getting popular in the industry. These methods have been able to reduce the lead time, reduce costs and improve quality in the construction industry [32, 33]. When it comes to the housing retrofit industry, Energisprong has used prefabricated insulated panels to improve

the overall installation efficiency. These panels are cut into the perfect sizes, transported to the site and assembled. This has reduced the installation time significantly. Further, as the building components are manufactured in factories and controlled environments, the quality of the products is higher and the waste is lower [11].

There were a range of government grants to support insulation for UK houses. Due to the failed insulation measures causing mould and dampness in retrofitted houses, people started to hesitate to retrofit their houses. This situation forced the government to focus more on improving the quality of the retrofit [34]. As a result of this, the Each Home Counts report was commissioned to investigate the situation. Based on the report recommendations, PAS 2035: 2019 was published and TrustMark was assigned to ensure the competency of the installers [35, 36]. These incidents happened over the past decade and led to the improvement of the skilled labour force, suitable for the quality delivery of retrofit.

As far as the current situation is concerned, the existing retrofit-at-scale strategies are observed to focus on capital-intensive approaches to retrofit. For example, the government expect to electrify heating in buildings and decarbonise the electricity supply to achieve their decarbonisation goals. Further, there are focuses on alternative methods such as Hydrogen or Carbon offsetting [19]. The government's interest is on the supply side of energy decarbonisation through capital-intensive approaches (E.g., Wind power, grid expansion, Hydrogen, Nuclear power or Carbon capture and storage), but not reducing the energy demand by retrofitting buildings [18].

The UK government prioritised energy security and net zero by establishing a separate ministry for that. Currently, the government is working on the "Clean Power 2030 Action Plan", to generate 95% of the electricity through renewable and nuclear sources in the UK. Further, they have established a public company called "Great British Energy" to drive this objective as well as to keep control of the energy market to the government [37].

5. What is the current situation related to labour-intensive approaches?

As far as the labour-intensive approaches are concerned, the industry seems to be running on labour-intensive approaches as there are no signs of mass-scale capital-intensive approaches to retrofit. Further, the retrofit industry is observed to suffer from a lack of skills in the industry [38, 39]. Another key highlight is the introduction of retrofit roles under the PAS 2035 specification [16]. There are five main professional roles to deliver housing retrofit. They are the retrofit assessor, retrofit coordinator, retrofit installer, retrofit designer and retrofit evaluator. The retrofit installations are covered under the specification of PAS 2030 [40]. The non-residential segment is covered by PAS 2038 specification, which is similar to the above [41]. Further, TrustMark (a not-for-profit organisation) has been given the authority to conduct the quality assurance of the installers [42].

The government allocated £ 8.85 million to train around 8,000 retrofit professionals in 2023 [43]. Further, various regional authorities allocated funds to train retrofit professionals under their budgets. However, there is no national-level funding in England and Wales for training people related to retrofit delivery at the time of writing this article. Low Energy Transformation Initiative argues that the government's focus is on achieving national-level decarbonisation targets rather than improving energy efficiency which will benefit individual residents more [18]. This approach may have been inspired by the Climate Change Committee's recommendation for the 6th carbon budget to go for a balanced pathway with 12% energy efficiency expected from the housing sector [44]. Focusing on the recent labour government's actions, it can be noted that the government's strategy is mainly aligned with the capital-intensive approaches as discussed in the previous section in detail.

6. What is the current situation related to capital-intensive approaches?

Capital-intensive approaches to housing retrofit have been in the discussion for some time in the United Kingdom. The adoption of technologies such as offsite construction is slow in the retrofit industry due to various reasons such as regulatory barriers, poor communication of problems related to quality assurance [45]. One of the reasons for the lack of interest in capital-intensive retrofit approaches can be the economies of scale. Since the industry is still immature, investors hesitate to go for capital-intensive approaches due to the uncertainty of the returns. To address these uncertainties and give confidence to the investors, new procurement methods emerged. This can be observed in the retrofit industry as well. For example, Energiesprong UK proposes an innovative partnership method of procurement. This promotes collaboration and a guaranteed market for innovative products and services [46]. A similar procurement method was tested in Italy to support innovations in retrofit called "Public Procurement of Innovation"[47].

Although not popular or established such as PAS 2035 or TrustMark installer certification schemes observed in labour-intensive approaches, several trends can be identified in capital-intensive approaches as well. Property tech companies such as CoreLogic have developed smart apps and desktop systems to facilitate the roles of retrofit professionals such as retrofit assessors or retrofit coordinators. The retrofit assessors can easily do their assessments with the help of apps and the retrofit coordinators can do their work efficiently with the desktop software [48, 49]. These systems can be considered as part of the automation of their work.

Another national-level initiative is digital building stock modelling. This initiative captures energy efficiency, visual, location and spatial details of the building stock through sensors. This is a government-funded £4 million project where the cameras and sensors are mounted on cars and drones to capture data. The purpose is to collect data regarding the existing building stock to help with decision-making [50]. There are some other capital-intensive initiatives observed about decarbonisation of energy, but

not exactly on retrofitting. The government has allocated budgets for Hydrogen testing, carbon capture technologies and nuclear power. The government also stated that they expect a major contribution to decarbonisation through innovation [19, 51].

7. *What would be the scenario of a labour-intensive retrofit delivery at scale?*

As the term suggests, the labour-intensive retrofit approaches will create more employment opportunities and this will reduce the unemployment rate. It is forecasted by PwC that retrofit will need 583,600 people from 2023 to 2030 [52]. The Construction Leadership Council states there will be 500,000 new jobs required up to 2035 [52]. Researchers argue that the industry is already suffering from a lack of skilled people to deliver retrofit projects even at the current poor demand level [38, 39]. This is validated by the fact that the building and construction industry has the highest level of skills shortages among all the sectors in the UK, which is 22% [53].

Considering these factors, a labour-intensive approach to retrofit can be considered risky, if there is no proper strategy to supply the skilled labour required for the existing and future demands. Compared with the capital-intensive approaches, labour-intensive approaches will also need some level of initial investment to train skilled workers and motivate people to shift to the construction industry. However, there will not be a requirement for a high initial training and development cost if the skilled labour is imported from abroad or if the people voluntarily start shifting to the construction and retrofit industries. If the labour is imported, this will also increase the requirement for housing.

Assuming there are no skill supply shortages, labour-intensive approaches will not need significant upfront investments. Considering the individual client requirements, researchers suggest having a rather human-centric approach to the homeowners considering the social interactions and relational aspects of housing retrofit [54-56]. Homeowners will be more motivated to consider retrofit with social interactions with their neighbourhood including the retrofit professionals [57, 58]. Due to the existing poor homeowner engagement with the housing retrofit [7], a labour-intensive approach will increase resident engagement.

Another important aspect that needs to be focused on is health and safety in construction. According to Health and Safety Executive UK, the construction industry is reported to have the highest rate of fatal accidents (37%) in the United Kingdom for 2023/2024, which is 51 out of a total of 138 incidents [59]. This can be a reason for the highest skilled shortages observed in the construction industry (22%) as mentioned above [53]. In a labour-intensive approach to retrofit, a higher number of health and safety incidents can be expected compared with a capital-intensive approach. The manufacturing industry has only 16 fatal accidents reported out of a total of 138 incidents [59].

8. *What would be the scenario of a capital-intensive retrofit delivery at scale?*

Considering the current skill shortage, the capital-intensive retrofit-at-scale approach will reduce the dependence on manual labour. Initiatives such as digital building stock modelling [50] will help to understand the existing building stock, their retrofit requirements and ideal retrofit scenarios. Prefabrication and offsite construction methods can be used to reduce the lead time, improve the construction quality, minimise waste and improve overall efficiency [32, 45]. In a capital-intensive approach, focusing on Design for Manufacturing and Assembly (DFMA), Lean supply chain management or modern methods of construction (MMC) approaches will be important. This has been currently focused by certifications such as Energiesprong [11]. They achieve their excellence through adopting offsite construction and prefabrication. Considering the positive side, there will be cost savings expected through improved efficiency. Another advantage is releasing the skilled workers (Currently in the construction supply chain) to retrofit the houses, improving the skilled labour supply in housing retrofit. Looking at the negative side of these capital-intensive methods, there can be risks of not receiving the expected benefits and high initial investments upfront.

In labour-intensive approaches, there will be people working closely with the clients. Accordingly, the individual-level requirements will be prioritised. In a capital-intensive approach, the focus will be on national objectives such as decarbonisation, which may not be individual requirements. That may demotivate people engaging positively with retrofit initiatives. This is already observed in the retrofit industry. The existing government focus is to reduce the energy efficiency levels of the houses to make heat pump installation feasible, ideally EPC "C" [19]. When the heat pumps are installed and the electricity is decarbonised, the government can achieve their decarbonisation targets. With such a level of energy efficiency, residents may not be relieved from fuel poverty [18].

The target energy efficiency of a house is below 90 kWh/m²/y from a nominal level of 200 - 300 kWh/m²/y to make heat pump installation feasible [60]. Electricity is nearly four times more expensive than natural gas [18]. Due to the situation, the resident can enjoy a low emission and more comfortable house, but at a higher level of energy cost [13]. This can put the resident into fuel poverty instead of relieving their energy bill burden.

9. *What are the advantages of these approaches?*

Both the labour-intensive and capital-intensive approaches have their advantages and disadvantages. Labour-intensive approaches can create employment. As the construction industry has the highest skilled shortages in the UK, this can worsen the skill shortage gap, converting the employment creation to a disadvantage. Labour-intensive approaches also improve the human interactions with the residents and the clients, which will motivate them to retrofit their houses more. This is a clear advantage of a labour-intensive approach considering the current poor demand for retrofit. The UK housing stock is highly diverse

and importantly older houses were not built under specific standards. The vernacular architecture style has increased this diversity. The characteristics and information about houses are mostly not available [61]. Due to these circumstances, a labour-intensive approach shall create a more personalised and careful approach to retrofit housing stock while preserving the heritage aspects and client preferences. It will also be able to achieve higher energy efficiency levels due to attention to detail possible with human expertise. One of the key disadvantages of a labour-driven strategy is the higher health and safety risks. The construction industry shows the highest rate of fatal accidents [59], this can be a critical point, unless actions are taken to mitigate such risks.

Capital-intensive approaches will be a solution to address existing skill shortage issues in the construction industry. Further, capital-intensive approaches will reduce the construction cost, waste, and project duration while improving the quality. According to [62], prefabricated house construction in the UK still has a long way to go as the current share is around 7.5%. In this situation, capital-intensive approaches will contribute not only to the retrofit industry but the overall construction industry. As earlier discussed, there is a question of to what extent these capital-intensive approaches are suitable for housing retrofit due to the diverse and unique nature of houses [3]. The current retrofit-at-scale initiatives focus on shallow retrofits to reduce energy efficiency only to a level feasible for installing heat pumps [19]. This will be complimentary with capital-intensive approaches. The high initial investments to set up these capital-intensive approaches are one of the challenges. Further, the risk of investments will also push the industry to hesitate to venture into capital-intensive approaches to retrofit.

10. *What is the recommended approach for the UK context, considering the national and individual requirements?*

Apart from the reduced energy bills, better health, better comfort, property value increase and other individual-level client requirements, there is a national-level requirement to reduce carbon emissions. The existing heat pump-based housing decarbonisation strategy will be complementary with a capital-intensive approach. It is doubtful whether it will address the individual client requirements or it will achieve a higher level of energy efficiency. The most critical risk is whether the residents will welcome such an approach, not focused on their requirements. In this consideration, a more resident-focused strategy is recommended.

Subject to a proper strategy for addressing the skills shortage, it is recommended to go for a labour-intensive approach to retrofit. This does not prevent topping up the operational efficiency through capital-intensive best practices.

Techniques such as modern methods of construction (MMC), innovative technical solutions or quick response manufacturing (QRM) are recommended for topping up labour-intensive approaches to retrofit. While keeping the mainstream approach as labour-intensive, capital-intensive approaches should help overall

efficiency and productivity. This can be started from the retrofit supply chain by focusing on better innovative products. Maybe, there will be a time when the labour-intensive approach can be diverted to a capital-intensive approach, subject to a strong demand for retrofit.

Modern Methods of Construction (MMC) rely on factory manufacturing of building components offsite and installation of them on-site [33]. The requirement for innovative technical solutions is highlighted by [18]. For example, using heat batteries sized to replace the boiler unit void when a boiler is replaced with a heat pump. Quick response manufacturing (QRM) focuses on reducing lead times in manufacturing for high-mix and low-volume environments [63]. Considering the nature of housing retrofit with smaller teams, several retrofit measures, the diverse nature of projects and the critical need to reduce lead time due to disruption to residents, QRM is suggested.

III. CONCLUSION

Assuming there are no issues with the technology and funding, the UK does not show clear progress to retrofit the total 30.1 million housing stock before 2050. A clear strategy is required to retrofit at scale. Looking from a project delivery perspective, two approaches can be identified: labour-intensive and capital-intensive.

By considering the individual and national level requirements, characteristics of these two approaches and the nature of the housing retrofit industry in the UK, a labour-intensive retrofit approach is recommended initially. As the number of housing retrofits increases, this may be transitioned into a capital-intensive approach later. This can be further topped up with capital-intensive techniques for better efficiency and productivity. The study recommends further exploration and discussion under this topic, due to the urgency of retrofit at scale.

It is noted that although there was some government interest in developing skills, the current initiatives are largely focusing on capital-intensive approaches to housing retrofit. This may be due to the multiple expectations of the government, as the construction industry is only one of them. Policy decisions are made considering broader socio-political and economic reasons.

REFERENCES

1. ONS, *Dwelling stock: by tenure, United Kingdom, as of 31 March*. 2022, Office for National Statistics: United Kingdom.
2. Butt, B., R.V. Jones, and A. Fuertes, *Opportunities and barriers to business engagement in the UK domestic retrofit sector: An industry perspective*. Building Services Engineering Research and Technology, 2021. **42**(3): p. 293-305.
3. BRETrust, *The Housing Stock of The United Kingdom*. 2020, www.bretrust.org.uk.
4. DESNZ, *Final UK greenhouse gas emissions national statistics: 1990 to 2022*. 2022.
5. National Energy Action, *Energy crisis*. National Energy Action (NEA), 2024.
6. The Health foundation, *How does housing influence our health? | The Health Foundation*. The Health Foundation, 2017.
7. Holms, C., *Demand: Net Zero Tackling the barriers to increased homeowner demand for retrofit measures*. 2023.

8. Skidmore, C. and S. McWhirter, *Mission Retrofit*, in *UKGBC*. 2023.
9. MCS. *Record number of heat pumps installed in UK homes in 2023*. 2024; Available from: <https://mcsfoundation.org.uk/news/record-number-of-heat-pumps-installed-in-uk-homes-in-2023/>.
10. Traynor, J., *EnerPHit: A Step by Step Guide to Low Energy Retrofit*. 2019: Routledge.
11. Energiesprong, *Energiesprong explained – Energiesprong*. Energiesprong.org, 2019.
12. Paillet, T., *The big push for retrofit in UK housing*. ww3.rics.org, 2024.
13. Panakaduwa, C., P. Coates, and M. Munir, *Evaluation of Government Actions Discouraging Housing Energy Retrofit in the UK: A Critical Review*, in *European Energy Markets 2024*. 2024: Istanbul, Turkey.
14. Burnett, N., I. Stewart, and S. Hinson, *The UK's plans and progress to reach net zero by 2050*. House of Commons Library, 2024.
15. Galvin, R. and M. Sunikka-Blank, *Ten questions concerning sustainable domestic thermal retrofit policy research*. Building and Environment, 2017. **118**: p. 377-388.
16. BSI, *PAS 2035:2023 Retrofitting dwellings for improved energy efficiency. Specification and guidance*. 2023, British Standards Institution: United Kingdom.
17. LETI, *LETI Climate Emergency Retrofit Guide*. 2021, www.leti.london.
18. Twinn, C., *Retrofit at Scale*. Sdfoundation.org.uk, 2024.
19. DBEIS, *Heat and buildings strategy*. GOV.UK, 2021.
20. Simcock, N., G. Walker, and R. Day, *Fuel poverty in the UK: beyond heating?* People Place and Policy Online, 2016. **10**(1): p. 25-41.
21. Garrett, H., et al., *The cost of poor housing in England 2021 Briefing paper*, in www.bregroup.com. 2021, Building Research Establishment.
22. Frankema, E., *Labour-intensive industrialization in global history: a review essay*. Economic History of Developing Regions, 2015. **30**(1): p. 44-67.
23. Thomas Ng, S. and Z. Tang, *Labour-intensive construction sub-contractors: Their critical success factors*. International Journal of Project Management, 2010. **28**(7): p. 732-740.
24. Clough, H., *Digital transformation in construction: Why is the industry slow to adopt digital compared with others?* Planning, Building & Construction Today, 2024.
25. Fernandes, J.M.C., *Productivity Levels in Portugal: Capital-intensive Industries Vs. Labor-intensive Industries*. 2024, Universidade do Porto (Portugal): Portugal. p. 89.
26. Kasper, J., *Modernizing Capital-Intensive Industries with a Digital Thread | Manufacturing Tomorrow*. Manufacturingtomorrow.com, 2014.
27. Babalola, O., E.O. Ibem, and I.C. Ezema, *Implementation of lean practices in the construction industry: A systematic review*. Building and environment, 2019. **148**: p. 34-43.
28. Montazeri, S., Z. Lei, and N. Odo *Design for Manufacturing and Assembly (DfMA) in Construction: A Holistic Review of Current Trends and Future Directions*. Buildings, 2024. **14**, DOI: 10.3390/buildings14010285.
29. Riley, M. and A. Cotgrave, *Construction Technology 1: House Construction*. 4 ed. 2018: Oxford Macmillan Education Red Globe Press.
30. Mao, C., et al., *Comparative study of greenhouse gas emissions between off-site prefabrication and conventional construction methods: Two case studies of residential projects*. Energy and Buildings, 2013. **66**: p. 165-176.
31. Thornton, M., et al., *How manufacturers are adopting Industry 4.0 in Europe*. RSM Global, 2024.
32. Cartlidge, D.P., *Construction project manager's pocket book*. 2020: Routledge.
33. Marshall, D., et al., *The construction of houses*. 5 ed. 2013: Routledge.
34. Rosenow, J. and N. Eyre, *A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy*. Energy Research & Social Science, 2016. **21**: p. 141-144.
35. Rickaby, P., *The importance of standards for safe energy retrofit | A BSI white paper*. 2023, British Standards Institute.
36. Bonfield, P., *Each Home Counts*. 2016, Department for Business, Energy and Industrial Strategy (BEIS) and Department for Communities and Local Government (DCLG): United Kingdom.
37. UK Government, *Clean Power 2030 Action Plan: A new era of clean electricity*. 2024, Department for Energy Security and Net Zero: United Kingdom.
38. Nanda, A., et al., *Retrofitting housing: Translating net-zero commitments into actions and impacts*. research.manchester.ac.uk. 2022: University of Manchester.
39. DBEIS, *International review of domestic retrofit supply chains*, in www.assets.publishing.service.gov.uk. 2021, Open Government Licence.
40. BSI, *PAS 2030:2023 Energy efficiency in existing dwellings*. 2023, British Standards Institution: United Kingdom.
41. BSI, *PAS 2038: 2021 Retrofitting non-domestic buildings for improved energy efficiency. Specification*. knowledge.bsigroup.com, 2021.
42. TrustMark, *TrustMark - About Us*. www.trustmark.org.uk, 2022.
43. Desnz, *Thousands to be trained to boost energy efficiency in homes across the country*. GOV.UK, 2023.
44. CCC, *The Sixth Carbon Budget*, in www.theccc.org.uk. 2020, Climate Change Committee.
45. Duran, Ö., *Offsite Construction for Mass-Retrofit: Barriers and Opportunities*, in *Innovations, Disruptions and Future Trends in the Global Construction Industry*. Routledge. p. 185-198.
46. Braham, E., *Energiesprong UK*. Energiesprong.uk, 2023.
47. Deambrogio, E., et al., *Increase sustainability in buildings through Public Procurements: the PROLITE project for lighting retrofit in schools*. Energy Procedia, 2017. **111**: p. 328-337.
48. CoreLogic. *PAS Hub - Web based workflow management system to enable the delivery of PAS 2035 and ECO compliant measures*. 2023; Available from: <https://www.corelogic.uk/products/pas-hub/>.
49. CoreLogic. *PAS 2035 Retrofit App*. 2023; Available from: <https://www.corelogic.uk/products/pas-2035-retrofit-app/>.
50. Cuff, M., *Millions of UK homes scanned for energy leaks to help reach net zero*, in *New Scientist*. 2024.
51. HM Government, *Powering Up Britain*. 2023.
52. PwC, *Green Skills as Enabler for UK Retrofit*. www.pwc.co.uk, 2023.
53. Industrial Strategy Council, *UK Skills Mismatch in 2030*. industrialstrategycouncil.org, 2019.
54. Bolton, E., et al., *The relational dimensions of renovation: Implications for retrofit policy*. Energy Research & Social Science, 2023. **96**.
55. Ebrahimigharehbaghi, S., et al., *Application of cumulative prospect theory in understanding energy retrofit decision: A study of homeowners in the Netherlands*. Energy and Buildings, 2022. **261**.
56. Bobrova, Y., G. Papachristos, and L.F. Chiu, *Homeowner low carbon retrofits: Implications for future UK policy*. Energy Policy, 2021. **155**(1): p. 112344.
57. Fransman, R. and A.v. Timmeren, *Psychological and social factors underlying pro-environmental behaviour of residents after building retrofits in the City-zen project*. Energy Procedia, 2017. **122**: p. 1051-1056.
58. DellaValle, N., A. Bisello, and J. Balest, *In search of behavioural and social levers for effective social housing retrofit programs*. Energy and Buildings, 2018. **172**: p. 517-524.
59. HSE, *Statistics - Fatal injuries in Great Britain 2023/24*. Hse.gov.uk, 2024.
60. SHRA, *Procurement Toolkit*. 2022, Social Housing Retrofit Accelerator.
61. Panakaduwa, C., P. Coates, and M. Munir, *Identifying sustainable retrofit challenges of historical Buildings: A systematic review*. Energy and Buildings, 2024. **313**: p. 114226.
62. Inkwood, *UNITED KINGDOM PREFABRICATED CONSTRUCTION MARKET FORECAST 2023-2030*. Inkwood Research, 2024.
63. Suri, R., *Quick Response Manufacturing*. 2020: CRC Press.