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Serial retrofitting as a bottom-up innovation for sustainability: Application of the multi-level perspective

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Serial retrofitting represents a crucial advancement in urban sustainability, addressing cost increases, resource constraints, and labour shortages within the building sector. “Energiesprong Deutschland”, coordinated by the German Energy Agency (dena), is a pioneering initiative for the retrofitting of 1950s–1970s multi-family housing through cost- and time-efficient solutions utilising industrial prefabrication and standardised components.

Within the study, the role of serial retrofitting as a transformative innovation within the energy transition is assessed using Geels’ multi-level perspective, examining its establishment and potential for future system change within the context of the “Great Transformation”. The analysis reveals six interdependent feedback loops governing diffusion dynamics: performance monitoring, scalability dynamics, financial maturation, market co-evolution, market acceptance, and social acceptance.

Serial retrofitting remains positioned within the early diffusion phase of the multi-level perspective framework. The study identifies three targeted intervention pathways: regulatory harmonisation, cultural transformation within the construction sector and innovative financing mechanisms. To expedite regime reconfiguration, various measures are required at political, institutional, social, cultural, research, and market levels. Serial retrofitting offers a future-oriented solution for transforming the building sector in alignment with the political agenda. By combining integrated technical, economic, and social efforts, it promises significant contributions to the decarbonisation and sustainable development of the building stock.

Keywords: energy transition, retrofitting measures, building stock, multi-level perspective, urban sustainability

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Introduction

The energy transition represents one of the greatest challenges of the 21st century, with the building sector being a critical focus due to its contribution of 40 % of energy consumption and 36 % of greenhouse gas emissions globally (Königstein, 2024). In Germany, the building sector accounts for approximately one-third of CO_2 emissions (Thamling et al., 2023).

Adopted in 2015 as part of the UN Climate Change Conference, the Paris Climate Agreement is a multilateral treaty that obliges signatory states to limit the increase in global average temperature to below 2°C compared to pre-industrial levels (UNFCCC, 2023). The “European Green Deal” (EGD), a key component of the European Union’s “Agenda 2030”, aims for greenhouse gas neutrality by 2050. This target is legally binding under the provisions of the European Climate Law (EU, 2023; Schubert et al., 2023). A particular emphasis is placed on the promotion of energy efficiency and affordability in existing buildings and on the “Renovation Wave” strategy, which aims to increase the renovation rate from 1 % to 2 % by 2030. Additionally, the Energy Performance of Buildings Directive (EPBD) aims to establish a harmonised system of energy efficiency classes across the EU. This directive focuses on buildings with the highest energy consumption, categorised as “worst performing buildings” (WPB) (EC, 2020; BPIE, 2024).

Germany has aligned its climate protection goals with these international commitments. The Climate Protection Act of 2019 sets binding targets for reducing emissions and establishes a path to net greenhouse gas neutrality by 2045. It mandates reducing greenhouse gas emissions by at least 65 % by 2030 and 88 % by 2040 (Umweltbundesamt, 2023). Germany has established building energy efficiency requirements in phases since 1977, beginning with prescriptive thermal standards and evolving to performance-based codes following EU directives in 2002. The Building Energy Act (GEG) aims to reduce energy consumption and CO_2 emissions in the building sector whilst encouraging the use of renewable energies (EnEV-online, 2020). Furthermore, the Climate Action Programme 2030, initiated in 2019, contains interdisciplinary measures to reduce CO_2 emissions, including the implementation of a carbon price for transport and heating (Bundesregierung, 2019).

Since its inception in 2017, the German Energy Agency “Deutsche Energie-Agentur (dena)”, supported by the German Federal Ministry for Economic Affairs and Energy, has been addressing these challenges through the “Energiesprong Deutschland” initiative by developing a new market sector within the retrofitting industry. In Germany, serial retrofitting focuses on multi-family houses built between the 1950s and 1970s, which account for 53 % of German households (Schumacher et al., 2023). Following the successful completion of the pilot phase, the innovative retrofitting approach is planned to be extended to other building types. Whilst the Netherlands has progressed beyond the pilot phase, similar initiatives are developing in France, the UK, Italy, Canada and the United States (Hermann et al., 2021; Energiesprong International, 2023).

Current state of serial retrofitting in Germany

Germany has adopted the Dutch “Stroomversnelling” strategy, which was launched in 2010 to renovate high-consumption buildings to net-zero standard. This strategy involves using digitalised and standardised processes, prefabricated roof and facade modules, and modernising building technology (dena, 2023). This approach, known as serial retrofitting, addresses labour shortages, gas dependency, and rising inflation and energy costs whilst promoting low-carbon urban development.

In Germany, "Energiesprong" acts as an independent market development team assisting housing and construction companies in developing advanced retrofitting solutions. The building's suitability is evaluated based on specific criteria including storey count, building cubage, solar-to-living space ratio, minimum living space of 1.000 square metres, and energy consumption of approximately 130 kWh/(m²a) (dena, 2024). The retrofitting process begins with precise 3D measurement to create a "digital twin", followed by digitised planning and prefabrication of modules. The facade and roof modules are prefabricated to reduce on-site time and minimise disruption for tenants. After on-site assembly of the prefabricated modules, the monitoring phase begins (Hörnemann, 2023). Based on these requirements, the German market comprises an estimated 500.000 suitable buildings with three million residential units, representing an estimated market volume exceeding €100 billion (Yildiz et al., 2022). Projections indicate potential savings of 158 TWh in final energy and around 36 Mt of CO_2 between 2022 and 2050 (Hermann et al., 2021).

Currently in the initiative's pilot phase, eleven projects (194 residential units) have already been successfully completed as of June 2023, with twelve projects (433 residential units) under implementation and a further 102 projects (9.496 residential units) in the planning phase (dena, 2023). The pilot projects are promoted in a targeted manner to raise awareness of the benefits and potential and to encourage service providers to enter the market segment.

Financial support mechanisms include Europe-wide funding instruments, such as the "Interreg Mustbe0" programme, which supported the first pilot projects (Interreg, 2021). Germany's "Federal Funding Programme for Efficient Buildings" (BEG) provides loan subsidies and repayment incentives for nationwide projects, alongside specialised bonuses for serial retrofitting (e.g. EE Class Bonus, SerSan Bonus) and worst-performing buildings (WPB bonus) (ÖkoZentrum NRW, 2023). Additional funding has been allocated by the Federal Ministry of Economics and Climate Protection (BMWK) through the "Federal Funding for Serial Retrofitting" programme and state-specific subsidies such as North Rhine-Westphalia's "RL MOD NRW 2023". In combination with the federal subsidy, repayment discounts of up to 55 % are available (BAFA, 2023; MHKBD NRW, 2023).

Literature reviews on sustainable and serial retrofitting

The need for sustainable building retrofitting as a pillar of the energy transition is widely recognised in both academic and policy discourse. A substantial body of research has demonstrated that the retrofitting of energy-inefficient buildings contributes to a reduction in the carbon footprint, thereby ensuring greater future-proofing of buildings and reducing dependence on fossil fuels (Königstein, 2024; Eßmann et al., 2022; Helmrich et al., 2021). Furthermore, the retrofitting of energy-inefficient buildings has been demonstrated to provide long-term economic benefits through savings in energy and operating costs (Galvin, 2023; Sebi et al., 2018; Henger et al., 2017).

When looking more closely at the topic of serial retrofitting, we can find a large number of market studies and publications on the barriers and potentials for serial retrofitting of the German multi-family building stock. Existing studies predominantly focus on market dynamics. These studies quantify the green premium for energy-efficient properties and project cost savings through industrialised retrofitting methods such as prefabricated facades and modular components (Agora Energiewende et al., 2024; Yildiz et al., 2022; Hermann et al., 2021). However, they focus primarily on economic and technical paradigms. The emphasis falls on quantifiable outcomes such as CO_2 reduction targets or scalability challenges (e.g. shortage of skilled labour, federalism, supply bottlenecks). Less attention is paid to the transformation process itself. Nevertheless, this is crucial for comprehending whether a niche innovation can transform into systemic change and how serial retrofitting can influence future systems. To date, the transformation process of serial retrofitting has not been analysed in the existing literature—a gap that this study addresses using the multi-level perspective (MLP).

Objective

Within the study, serial retrofitting is assessed as a transformative innovation towards the “Great Transformation” (see below) in Germany. This study applies Geels’ (2002) multi-level perspective to analyse how serial retrofitting transitions from niche innovation to regime reconfiguration in Germany’s building sector. It examines the interdependencies between niche innovations, regime structures, and landscape pressures as well as phase-specific barriers to diffusion, including economic, institutional, and cultural challenges. Policy-industry interventions required to align funding mechanisms, regulatory frameworks, and stakeholder incentives with Germany’s 2045 decarbonisation targets are also examined. By integrating the MLP framework with case studies, the study aims to identify leverage points for accelerating systemic adoption while critically evaluating the approach’s limitations in addressing socio-political dynamics.

Procedure and methodology

In this study, serial retrofitting is examined with a particular focus on energy transition. To fulfil the study's objective, a step-by-step approach is taken. First, serial retrofitting is defined as a transformative innovation based on the characteristics of the Wuppertal Institute for Climate, Environment and Energy (Fischedick et al., 2021). Second, the MLP framework is applied to provide an abstract view of serial retrofitting in a socio-technical system. This allows for a conceptual mapping of the complex, multi-dimensional interactions that lead to transformation at the level of building construction, through interfaces with civil society, culture, politics, industry, technology, and the market. The comprehensive application of the MLP framework was enabled by the literature review, market analysis and stakeholder interviews, which provided empirical data to analyse the interactions between niche innovations, regime structures and landscape pressures.

This study employed a triangulated approach comprising literature research, market analysis, and expert interviews to examine the German serial retrofitting market. The literature review followed a systematic methodology, prioritising peer-reviewed articles and reports from recognised institutions, such as the German Energy Agency (dena), published between 2015–2025, to capture contemporary developments in sustainable building modernisation and serial retrofitting.

The market analysis focused on German multi-family housing constructed between 1950 and 1970, as these structures require urgent energy-efficient retrofitting and constitute a significant portion of the residential building stock (Statistisches Bundesamt, 2022). As part of the market analysis, 14 pilot projects implemented by eight total solution providers, each specialising in a unique approach, were analysed in order to assess the practical implementation and potential of serial retrofitting. The pilot projects were systematically documented in the form of case studies. Each case study describes the project and provides general information about the project size and the stakeholders involved. The measures implemented were listed and categorised by building envelope and system technology. A comparative analysis of the projects was undertaken to gain insights into the supplier market and technological innovation integration.

The empirical study employed a qualitative research design, using semi-structured and semi-qualitative expert interviews as the primary methodological approach. The interviews incorporated a set of standard questions derived from a preliminary questionnaire, complemented by open-ended discussion components. This approach was designed to facilitate the participants' elaboration on their experiences and perspectives. The interview guide was developed both deductively from the study's objectives and inductively from the existing literature. The guidelines covered topics such as planning and execution challenges, optimisation potentials and success factors in serial retrofitting. Five respondents participated in in-depth online interviews lasting between 50 and 90 minutes. The participants were selected based on their involvement in the previously conducted case studies and their demonstrated expertise as industry professionals in serial retrofitting. Selection criteria included direct experience with prefabricated retrofit projects, decision-making roles, and active participation in project leadership positions. The participants came from different backgrounds such as engineering and business economics, ensuring diverse professional perspectives on technical and economic aspects of serial retrofitting. The sample encompassed diversity across company types, organisational scales and market approaches within the German serial retrofitting sector. Respondents represented various business models and organisational structures, ranging from established market participants to innovative specialist providers. In consideration of the emergent status of the German serial retrofitting market in June 2023, theoretical saturation was achieved efficiently as the limited number of active market participants enabled comprehensive coverage of key stakeholder perspectives.

Data was collected through audio recordings, followed by transcription and analysis using MAXQDA software. The qualitative content analysis (according to Kuckartz and Rädiker, 2022) allowed for a systematic categorisation of statements into hierarchical categories. This approach identified recurring themes central to the interaction between niche and regime, ensuring an in-depth analysis of the data and a foundation for developing interventions to scale up serial retrofitting in the German market.

Transformation research

This study adopts the Wuppertal Institute's concept of "transformation research". Transformation research seeks to address societal impacts of climate change by framing them within the so-called "Great Transformation" (Fischedick et al., 2021). The term "Great Transformation", coined in 2011 by the German Advisory Council on Global Change (WBGU), describes a far-reaching process of ecological, technological, economic, institutional, and cultural upheaval in the 21st century. The need for transformation is urgent due to the impact of climate change on society, which provides a limited timeframe for the transformation process. The transformation requires the involvement of all relevant stakeholders, who share the responsibility for implementing the transformation processes (Schneidewind, 2019).

A transformative innovation is defined as having global and long-term transferability to society, either directly or indirectly, due to its complexity and high leverage effect. Such innovations employ radical approaches to achieve greenhouse gas neutrality and resource conservation and prioritise high-impact changes that have the potential to shape or transform systems (Fischedick et al., 2021). This study analyses the characteristics identified by the Wuppertal Institute in relation to serial retrofitting.

Multi-level perspective

In the study, the multi-level perspective is used to analyse a complex transformation process of a socio-technical system. The MLP is a theoretical analysis tool that simplifies the complexity, multi-layered nature and non-simultaneity of transformation processes. It combines a systemic perspective and self-dynamic processes with an actor's perspective to depict the scope for action, thus enabling the understanding of comprehensive transformation processes through abstraction. The application of the MLP in this study enables the categorisation of the socio-technical system and the consideration of the current status of market implementation, as well as the relevant impulses for reconfiguration of the regime. The MLP distinguishes between three levels of system transitions (see Figure 1), which are in constant interaction and mutually influence each other, thereby enabling the analysis of interactions between developments from niches and changes to the landscape level (Schneidewind, 2019; Best, 2019).

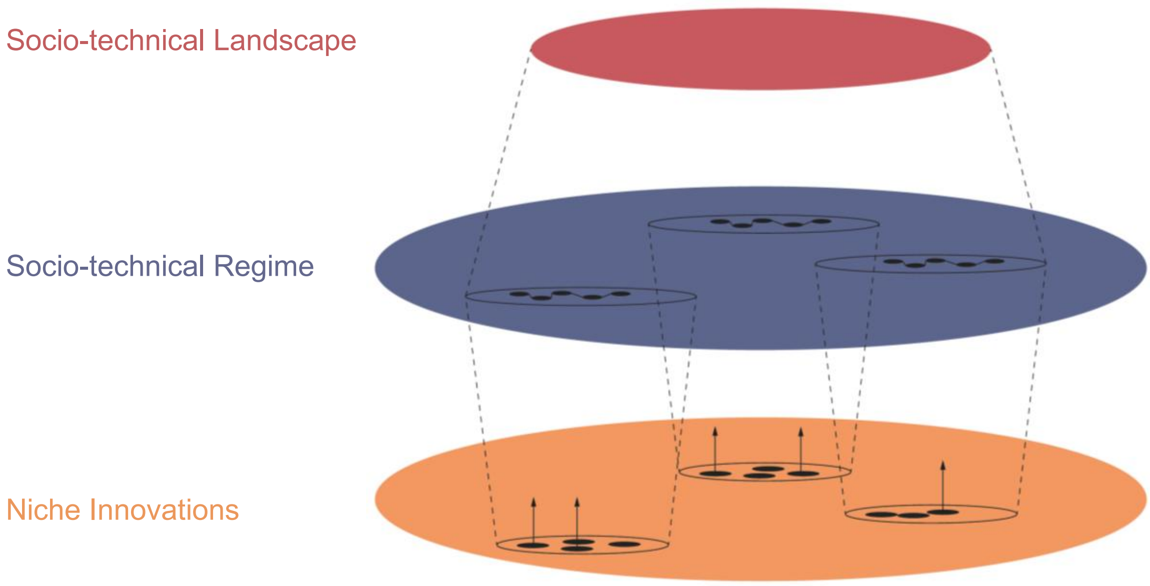

Figure 1*. Levels of the MLP. Authors' illustration based on Geels (2002, p. 1261)*

"Socio-technical Landscape": This level refers to the fundamental and overarching developments and trends that are difficult to influence in the long term. It represents a stable process that is characterised by everyday experiences and long-term developments. Global power shifts, economic crises, wars, and environmental changes have a significant impact on the subsystems, determining the direction and pace of transformation processes.

"Socio-technical Regime": This level describes the institutional structures in place. Changes may progress slowly due to the framework that maintains the status quo and restricts the scaling or spread of innovations. Transformation processes take place at the regime level and result from the mutual influence of all three levels. Therefore, the regime level is defined as the central observation level. When so-called "windows of opportunity" open up, the regime can be influenced by the impact of niches or transformation processes.

"Niche": This level refers to technological innovations aimed at social change, which involve "deviations" from existing structures. Niches play a crucial role in transformational change, and the influence of their innovations is maximised when they are independent of surrounding systems: This level allows learning and development processes to take place in a protected framework and provide shelter for innovations that may not yet be selected by the mainstream market.

The MLP has been widely adopted for the analysis of socio-technical transitions. While the framework provides a structured approach to understanding niche-regime-landscape interactions, its application reveals theoretical and methodological limitations that require critical examination (Geels, 2019). A primary critique focuses on the technological bias of the framework. Critics argue that the model overemphasises technological advancements, while neglecting social and political factors (Bögel et al., 2022; Geels, 2020). Moreover, the model's deterministic approach, where transformation processes are assumed to follow a predetermined transition path structured around linear phases of emergence, diffusion and reconfiguration, has been criticised for its potential to oversimplify the complex, contested nature of real-world transitions (Olbrich et al., 2024). Critics also note that the model is not explicitly validated through the use of empirical data (Cherp et al., 2018).

Whilst the technological focus and phased structure of the MLP are open to criticism, these limitations are addressed by the adapted application in three ways. First, the analysis integrates findings from market stakeholder interviews. Second, the study describes non-linear feedback loops in the diffusion of the retrofitting approach. Third, the study proposes suitable interventions to promote acceptance and broad implementation. The theoretical framework of the MLP is thus well suited for analysing serial retrofitting in the context of the energy transition and is able to deliver important results despite the admitted theoretical simplifications. The combination of semi-qualitative interviews with a market analysis was chosen in order to capture the subjective challenges of the stakeholders (interviews) on the one hand and the structural market dynamics (market analysis) on the other. This methodological approach was undertaken to facilitate a nuanced and comprehensive understanding of the intricate interactions between niche regimes.

Application of the methodology: Bridging the MLP framework and empirical insights

Examination of the characteristics

To qualify as a transformation process, serial retrofitting must fulfil the characteristics defined by the by the Wuppertal Institute mentioned above (Fischedick et al., 2021).

Significant contribution to greenhouse gas neutrality and resource conservation

Serial retrofitting addresses the urgent need to decarbonise Germany's residential building stock by targeting energy-intensive multi-family houses. The approach uses prefabricated modules and integrated renewable energy to reduce operational energy demand, embodied carbon, and fossil fuel reliance. Empirical evidence from pilot projects has demonstrated a reduction in transmission heat losses and overall heating energy consumption, thereby contributing significantly to the achievement of climate neutrality goals. However, achieving broader implementation requires policies that incentivise the use of sustainable materials and mandate lifecycle carbon accounting in retrofitting projects.

High impact depth instead of niche impact

Pilot projects, such as the LEG Living Lab (Gottschalk, 2020), have demonstrated the potential for serial retrofitting to be scaled from buildings to neighbourhoods, thus addressing both energy efficiency and social equity. Stakeholder interviews highlight the potential for enhancing housing quality while aligning with Germany's 2045 climate goals. However, barriers such as regulatory delays and limited funding must be addressed (Mauel et al., 2024). To facilitate the adoption of this approach at scale, policymakers should consider streamlining permitting processes, expanding funding programmes such as RL MOD NRW, and fostering public-private partnerships.

Radical disruptive innovations instead of incremental innovations

Serial retrofitting integrates digital technologies and prefabrication, marking a paradigm shift in construction. The approach has been shown to reduce project timelines and enhance cost efficiency, addressing critical challenges such as labour shortages and rising material and energy costs. Systematic solution approaches and holistic considerations aim to create synergies for economic viability and efficiency gains. Nevertheless, stakeholder resistance to digitalisation remains a barrier. The adoption of targeted training programmes and subsidies for the implementation of digital tools are identified as a key strategy to foster industry-wide acceptance of these innovations.

System innovations instead of a purely technological approach

The success of serial retrofitting depends on its holistic approach that integrates technological advancements with tenant well-being and value chain optimisation. Monitoring systems and tenant management align retrofitting with environmental goals and tenant satisfaction. Policy interventions must prioritise cross-sectoral collaboration, incentivise circular economy practices, and establish platforms for knowledge exchange among stakeholders.

System-changing or system-shaping character

Serial retrofitting has begun to reshape the construction industry by introducing new market players, including start-ups focused on innovative solutions. The industry adapts to political demands by developing production capacities, which drive both temporal scalability and efficiency. Systemic transformation is further supported by political support in the form of funding programmes such as the "Federal Funding Programme for Efficient Buildings" (BEG) and the "Federal Funding for Serial Retrofitting" (BMWK) programme. Policymakers must reduce market uncertainties through standardised frameworks for retrofitting components and long-term funding commitments.

Realistic feasibility

Pilot projects confirm the feasibility of serial retrofitting but reveal challenges in terms of cost competitiveness and rapid cost amortisation. The approach's technical feasibility is enhanced by its country-specific adaptation, addressing local needs and opening new markets for further development. Policymakers must promote international knowledge transfer and adapt funding mechanisms to support diverse market needs.

Application of the multi-level perspective

By analysing socio-technical transformation processes, conclusions can be drawn regarding the multidimensional interactions between society, culture, politics, industry, technology and the market. This conceptualisation of socio-technical systems is not a spatial analysis but an abstraction, with the three phases of the MLP being ideal-typical and frequently overlapping in practice (Schneidewind, 2019).

At the niche level, processes are driven by "pioneers" and society, focusing on integrating new technologies and products into conventional retrofitting practices—a development catalysed by current construction industry challenges. The different levels of transformation are intertwined and contribute to the gradual integration of niche innovations into the regime, thereby enabling systemic change. Public relations and inter- and transdisciplinary cooperation function as leverage mechanisms that can influence social and institutional value systems (Best, 2019).

In addition to the linear developments that can be observed within the MLP framework, non-linear feedback loops also play a central role. These loops emerge through iterative and recursive interactions between the three levels of the MLP. As illustrated in Figure 2, these loops are not static but dynamic and influence each other over time. For instance, technological innovation at the niche level can be reinforced by market reactions at the regime level. Concurrently, institutional adjustments at the landscape level establish novel framework conditions, which in turn exert a feedback effect on the niche and regime levels. These non-linear interactions result in developments, including scaling effects, path dependencies and emergent properties. These processes are of critical importance in understanding transitions in socio-technical systems, as they can have both accelerating and inhibiting effects (Vargo et al., 2020; Rogers et al., 2005).

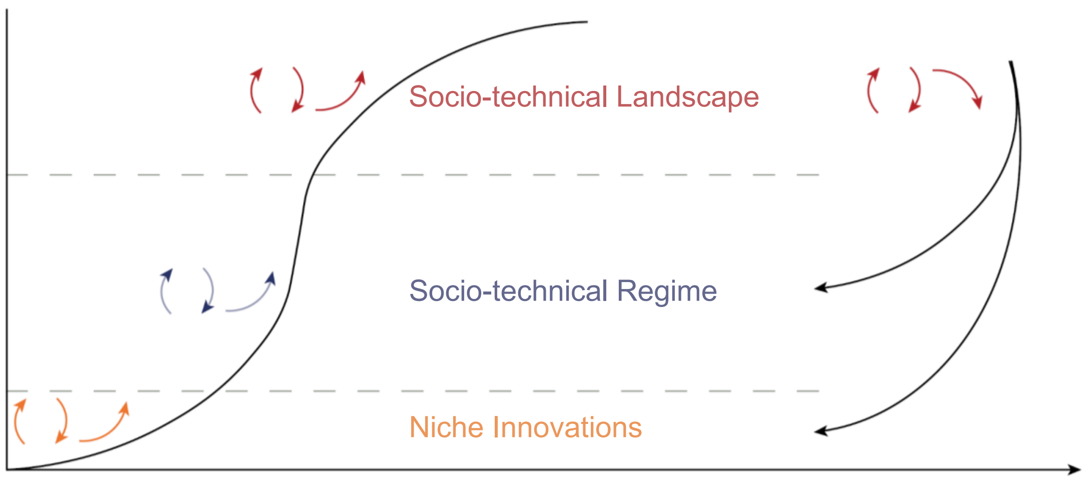

Figure 2. *Non-linear feedback loops in innovation diffusion. Authors' illustration based on Vargo et al. (2020, p. 532)*

Within the social subsystem "housing and infrastructure", serial retrofitting spans the three levels of the MLP and is defined by its social function, as buildings significantly influence quality of life and residents' wellbeing. Serial retrofitting represents a bottom-up transformative process initiated by long-term changes at the landscape level. The socio-technical regime consists of the building and utilities industry, user and implementation preferences, the orientation of market players, the training system for planners and the willingness of housing associations to invest (see Figure 3). The landscape level consists of the global trends and influencing factors that manifest themselves as external influences on the other levels. These include the climate crisis, the political agenda, the housing and energy crises as well as urbanisation, the shortage of skilled workers, inflation and rising energy costs.

The MLP is based on a dual-axis system. The horizontal axis represents the progression of time and the vertical axis represents the increasing structuring of social systems. The horizontal axis comprises three sequential phases. First, "emergence" occurs when an innovative technology or approach develops. Second, "diffusion" happens between the regime and niche levels as the system gradually changes. Third, "reconfiguration" takes place when a new regime emerges, shaped by long term niche influence (Victor et al., 2019).

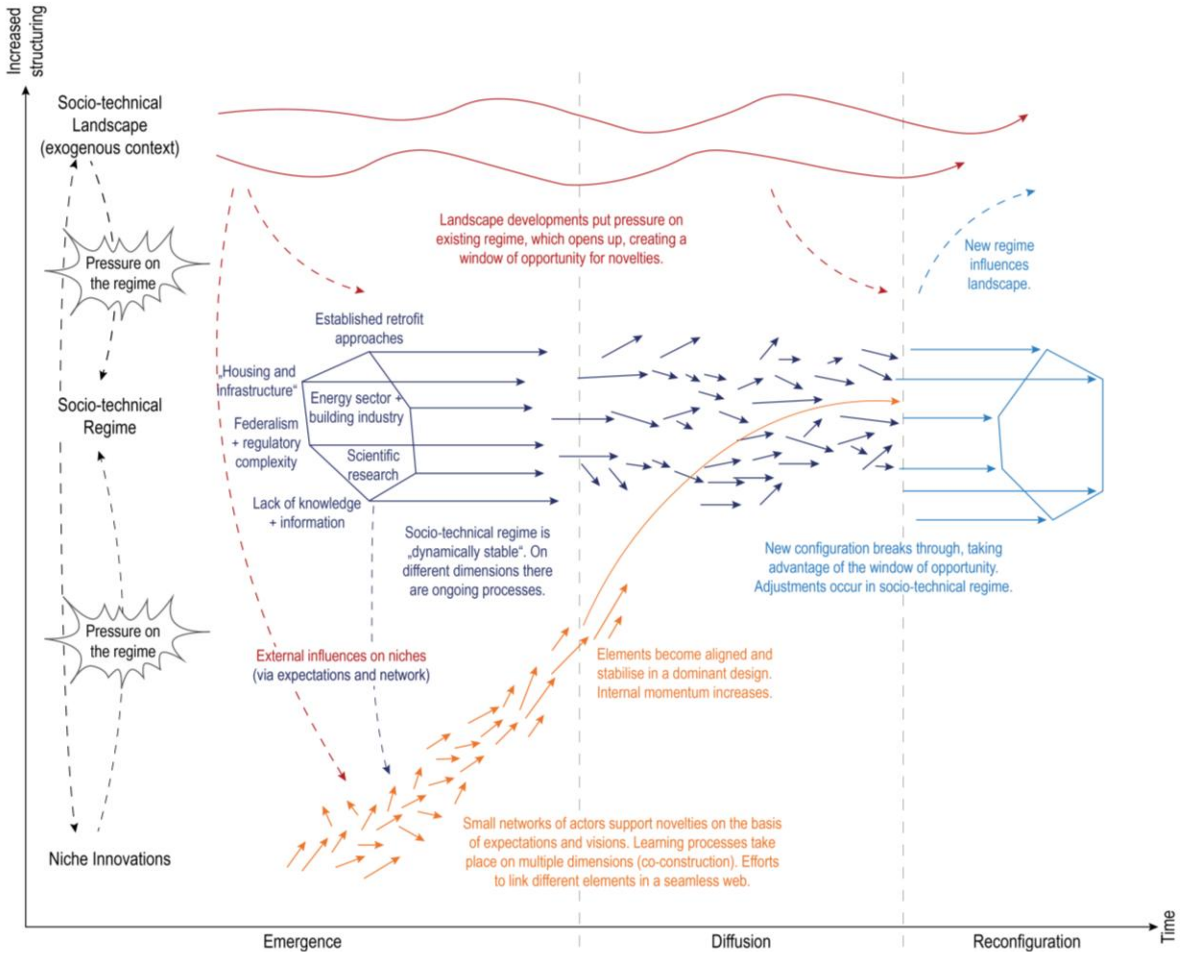

Figure 3. *Transformation process of niche innovations. Authors' illustration based on Geels (2002, p. 1263)*

As part of the market analysis presented earlier in the study, the structural framework conditions and dynamics of the supplier market, as well as the integration of innovative technologies, were assessed. The pilot projects are of particular relevance to this study, as they highlight the role of niche innovation and pioneering work. A detailed analysis of the project case studies provided insights into the technological and organisational approaches as well as the challenges and potentials of market entry. These findings were located at the niche level, as they represent the experimental phase of innovation and show how serial retrofitting is assessed as a new technology in a protected framework. The expert interviews conducted with industry stakeholders provided a valuable complement to the existing body of literature with qualitative data on the perceptions, challenges and opportunities of serial retrofitting. The results of the interviews enabled an in-depth analysis of the interactions between the niche and regime levels. Notably, the interviews exposed institutional impediments, including regulatory challenges and cultural resistance to digitalisation and innovation. These findings contributed to a more comprehensive understanding of the diffusion processes from the niche to the regime. Furthermore, the study assessed the influence of external factors, including political guidelines, on the transformation process.

Phase 1: Emergence

The emergence of serial retrofitting as a niche innovation is driven by landscape-level pressures, most notably the political narrative surrounding climate change. This pressure for change affects political, socio-economic and technological elements of the housing and infrastructure subsystem. Although climate change itself has not directly initiated the transformation process, the Paris Agreement and subsequent national commitments have translated environmental concerns into actionable policies. These include the establishment of more stringent energy standards, sectoral emission reduction targets, and regulatory frameworks aimed at decarbonising the building sector. Stakeholder interviews reveal that this political impulse has increased awareness among housing associations and market players of the urgency of sustainable retrofitting solutions. However, despite the strong interest in serial retrofitting, housing associations sometimes shy away from the high initial investment, illustrating the tension between niche and regime that is typical of MLP. In addition, there is an increasingly critical attitude among citizens towards fossil fuels and the use of non-renewable resources, as well as growing social awareness of sustainability, which is driving the need for innovation (see Figure 4).

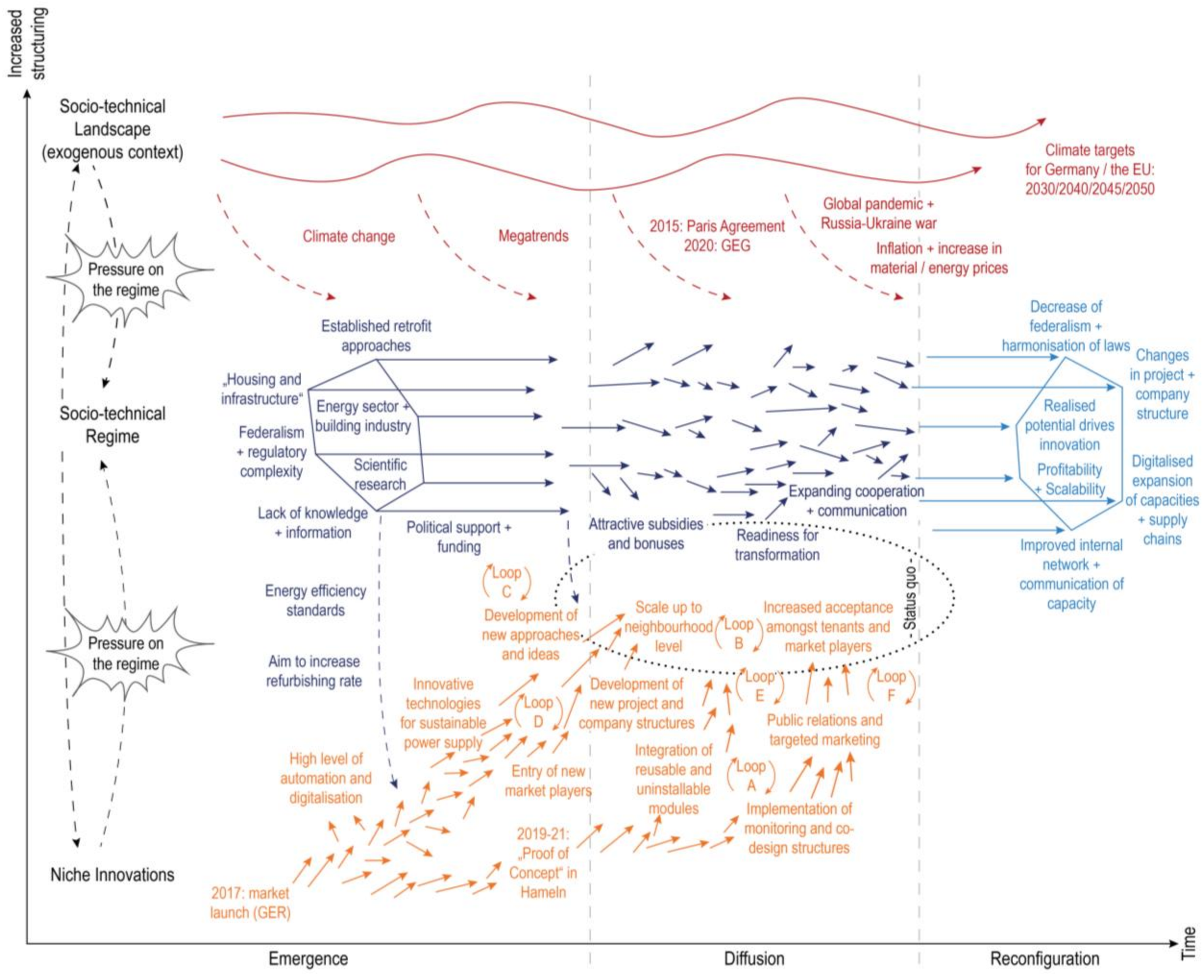

***Figure 4.** Transformation process of serial retrofitting. Authors' illustration based on Geels (2002, p. 1263)*

Moreover, the emergence phase of serial retrofitting is characterised by the initiation of pilot projects that serve as protected niche environments to evaluate technological and organisational innovations. Technological innovations are crucial to this phase: the integration of prefabrication processes, digitalised planning tools and renewable energy systems has enabled a shift towards serial retrofitting as a scalable approach. In contrast to conventional retrofitting, serial retrofitting uses industrialised workflows to streamline processes and reduce on-site disruptions. The market analysis, however, has identified significant obstacles that hinder the adoption of this approach on a broader scale. These include limited production capacities and substantial initial investment costs.

Phase 2: Diffusion

Serial retrofitting is currently transitioning from niche innovation to broader diffusion within Germany's socio-technical regime. Pilot projects, including those under the "LEG Living Lab" initiative, have demonstrated its scalability from individual buildings to neighbourhood-level retrofits and have served as the first signs of a reorganisation process. The pilot projects have demonstrated the potential for systemic change by integrating innovative technologies and fostering collaboration across value chains. For instance, neighbourhood-level retrofitting initiatives have been identified as opportunities for economies of scale and synergies with district heating systems.

Furthermore, large existing market players are adapting their companies towards serial retrofitting, and new market players are emerging. The competitive environment between companies is leading to increased innovation in technology, implementation, and design approaches to serial retrofitting. The factors contributing to the broad adoption of serial retrofitting are diverse, including rising energy and heating costs, a shortage of skilled workers, and increased information provided by market participants and dena.

As mentioned above, non-linear feedback loops are crucial to diffusion processes. In the context of serial retrofitting six interdependent feedback loops (A–F) could be identified through 14 case studies and five expert interviews. These loops collectively drive systemic change through dynamic interactions between technological, economic, and social factors (see Figure 4). The feedback loops can be categorised into two analytical categories, reflecting their primary operational domains within the socio-technical system. The system-building dynamics (Loops A–D) include supply-side mechanisms that construct and structure industrialised delivery capacity, such as performance learning (A), scale effects (B), financial maturation (C), and market co-evolution between specialised providers and regulatory frameworks (D). The dynamics of acceptance and adoption (Loops E–F) are concerned with the demand-side mechanisms that embed practice within organisations and communities. Market acceptance in housing associations (E) and social acceptance among tenants through co-design (F) are two such examples.

System-building dynamics

Loop A—Performance monitoring: Prefabricated modules become more efficient through recursive data exchange between digital twin simulations and building monitoring systems. This process enables iterative refinement of component standardisation, while hybrid manual-automated workflows accommodate building-specific irregularities. By analysing the planning and construction process, learnings can be drawn for the next project, work processes can be improved, and standardised solutions can be developed.

Loop B—Scalability dynamics: Costs can be decreased through economies of scale as project scale transitions from single buildings to neighbourhood clusters. This phenomenon, however, remains unevidenced in the current market analysis, likely due to the early stage of diffusion.

Stakeholders have suggested that bundled retrofits can reduce the manufacturing costs of facade and roof modules. Thereby reducing implementation costs and, indirectly, reducing apportionable costs for tenants. Over time, this can increase acceptance among tenants and promote the wider implementation of serial retrofitting.

Loop C—Financial maturation: The interdependency between cost efficiency and funding is rooted in the principle that the maturation of a given approach typically leads to enhanced operational efficiencies. As serial retrofitting becomes more established, economies of scale, optimised processes, and accumulated expertise will reduce overall implementation costs. Consequently, the reliance on high levels of external funding to overcome developmental challenges and establish infrastructure decreases over time.

Loop D—Market co-evolution: Furthermore, the emergence of new specialised solution providers shows how early success in a niche market can be a catalyst for competitive diversification. The diverse approaches illustrate how market entry triggers technological specification. This dynamic environment, in turn, exerts pressure on the regime level to adapt its regulatory framework in order to facilitate retrofitting and ensure compliance with the overarching requirements defined by the landscape.

Acceptance and adoption dynamics

Loop E—Market acceptance: Housing associations frequently favour established approaches due to their familiarity and perceived reliability. Information campaigns, such as those conducted by dena and market stakeholders, seek to demonstrate the technical feasibility of the approach through pilot projects. Successful implementations generate normative evidence that redefines innovation thresholds in housing governance frameworks. As more projects are successfully completed using serial retrofitting, the approach gradually gains acceptance within the industry, transitioning from being perceived as an “innovative” approach to becoming part of mainstream practice.

Loop F—Social acceptance: Tenant acceptance has been shown to increase when co-design mechanisms are used to incorporate tenant feedback and concerns into retrofit planning. This approach fosters a sense of inclusion and collaboration amongst residents. Housing associations can ensure transparent communication by explaining the benefits to tenants, such as reduced energy costs and higher building standards. By addressing potential fears or uncertainties early in the process, housing associations can reduce resistance and build trust among tenants. Such co-design mechanisms enable housing associations to modify serial retrofitting to align more closely with tenants’ wishes.

These non-linear feedback loops demonstrate mutual reinforcement across diffusion dynamics. Performance learning (A) supports scalability (B), which, when combined with process optimisation, enables financial maturation (C). Industry diversification and regulatory adaptation (D) sustain organisational acceptance (E). Furthermore, tenant acceptance (F) exerts a significant influence on organisational decisions, thereby encouraging continued investment in performance learning (A). Information flows from dena and market participants, thereby intensifying these interconnections across the regime.

In conclusion, the diffusion of serial retrofitting within Germany’s socio-technical regime has not yet been completed, with system transformation characterised by dynamic tensions between facilitating and constraining factors. Stakeholder interviews have highlighted the need for targeted communication strategies to foster acceptance of innovative practices. Although institutional support through funding programmes has facilitated early diffusion, existing funding and procurement frameworks require substantial enhancement for large-scale implementation. The findings indicate that without addressing these systemic constraints, large-scale implementation will remain limited despite positive developments in learning processes and stakeholder acceptance.

Phase 3: Reconfiguration

The reconfiguration phase remains aspirational, as serial retrofitting has yet to become cost-competitive with conventional modernisation methods or established as a routine practice within the regime. Stakeholder interviews have revealed persistent challenges, including lengthy administrative processes and discrepancies between client expectations and financial realities. Moreover, the ongoing presence of cultural resistance to innovation continues to hinder the widespread adoption of this approach.

This analytical investigation shows that serial retrofitting, as a transformative innovation, has the potential for systemic change. While active learning-by-monitoring and organisational acceptance facilitate uptake, underdeveloped economies of scale and emergent financial maturation constrain cost competitiveness. Market co-evolution and social acceptance are developing inconsistently across German regions and cities. Some housing markets advance faster in developing serial retrofitting capacity and gaining tenant acceptance, while others lag behind due to fragmented supply chains, varying state and municipal regulations, and persistent digitalisation scepticism within traditional construction firms. This uneven development hinders a uniform national rollout. Acknowledging this, it is important to recognise the need for targeted interventions across multiple levels in order to surpass the threshold for reconfiguration of the socio-technical regime. These interventions must be implemented at various levels, encompassing political and institutional changes, social and cultural shifts, and advancements in research and market improvements (Mauel et al., 2024). The implementation of such changes has the potential to stimulate market growth and generate a multiplier effect, which may result in a restructuring of the regime.

Results

Geels' (2002) multi-level perspective provides a robust framework for analysing the transformative potential of serial retrofitting, delineating its emergence as a niche innovation, the challenges of diffusion, and the aspirational reconfiguration of regimes. This section synthesises empirical findings from pilot projects and stakeholder interviews to map phase-specific barriers and propose targeted interventions aligned with socio-technical transitions. Serial retrofitting, as a transformative innovation, faces distinct barriers at each phase of its development within the socio-technical system. These barriers are rooted in economic, institutional, and cultural challenges, which hinder its progression from niche innovation to regime reconfiguration.

Barriers to systemic diffusion

The diffusion of serial retrofitting is characterised by significant institutional and market barriers that hinder its systemic integration. Housing associations, which hold a significant proportion of Germany's multi-family housing stock, are reluctant to adopt serial retrofitting due to the perceived risks associated with high upfront costs and untested processes. Stakeholder interviews reveal that housing associations continue to rely on established retrofit approaches, which compounds this reluctance. Housing associations perceive these established approaches as "safer" and "more dependable" despite the fact that they cannot meet climate targets independently. This conservative stance persists despite evidence from pilot projects and reports by institutions such as the German Energy Agency (dena, 2023) demonstrating serial retrofitting's capacity to achieve 80–90 % energy savings.

Stakeholder interviews reveal a paradox: while landscape pressures incentivise innovation, construction firms remain risk-averse due to the perception that serial retrofitting's inherent challenges are incompatible with existing workflows. Unlike traditional retrofit approaches, serial retrofitting requires changes to procurement processes, digitised planning and prefabrication, and on-site execution methods. Consequently, construction firms must integrate digital planning tools and prefabricated components into their workflows, a process which demands upskilling and cultural shifts within the industry.

Federalism further exacerbates these challenges. Germany's decentralised governance structure results in fragmented regulatory frameworks across the sixteen states, leading to disparities in building codes and permitting processes. These disparities make it more difficult for solution providers to implement standardisation. Moreover, prolonged approval timelines and administrative complexities extend serial retrofitting's normally short timeframes.

Economic barriers also persist. The social benefits of serial retrofitting, such as reduced energy poverty and enhanced living standards, remain unmonetised within current funding structures. Total solution providers encounter difficulties aligning client expectations with financial realities, as certain stakeholders are reluctant to shoulder the additional costs associated with these broader societal impacts. Process optimisation and economies of scale that could be realised if projects were to be bundled at neighbourhood levels remain unrealised.

Intervention pathways for accelerated regime reconfiguration

In order to overcome the identified barriers and accelerate the transition from diffusion to reconfiguration, a comprehensive set of intervention pathways needs to be implemented. These pathways should address the specific challenges at each level of the socio-technical system whilst fostering synergies between niche innovations, regime adaptation, and landscape pressures.

At the political and institutional level, the intervention framework should prioritise the harmonisation of regulatory frameworks amongst federal states in order to reduce administrative complexity and accelerate permitting processes. The research findings suggest that the establishment of a national standardisation framework for serial retrofitting components would significantly reduce market uncertainties and facilitate economies of scale. Furthermore, policy interventions should evolve beyond the current funding mechanisms to include a more nuanced approach that recognises and monetises the social benefits of serial retrofitting, such as reduced energy poverty and improved living standards.

Social and cultural interventions are equally crucial for overcoming resistance to innovation within the construction industry. The findings indicate that targeted training programmes and knowledge-sharing platforms would address the skills gap in digital planning and prefabrication. Furthermore, the use of co-design mechanisms that incorporate tenant feedback into retrofit planning would increase social acceptance, as evidenced by the positive feedback loop identified in the analysis of stakeholder interviews. The development of inclusive communication strategies that emphasise both the environmental and economic benefits of serial retrofitting would further contribute to wider acceptance among housing associations and tenants.

The findings also highlight the need for market-level interventions to address the economic barriers to uptake. The formation of public-private partnerships has the potential to reduce the financial burden on housing associations by sharing the initial investment costs. The establishment of neighbourhood-level retrofit programmes would enable economies of scale, thereby reducing the per-unit cost of serial retrofitting. Furthermore, the development of innovative financing mechanisms, such as energy performance contracting, would ensure that the financial incentives of the various stakeholders are aligned with the long-term benefits of serial retrofitting.

The six interdependent feedback loops identified in the MLP—performance monitoring, scalability dynamics, financial maturation, market co-evolution, market acceptance, and social acceptance—provide a framework for understanding how these interventions can reinforce one another. For instance, improved performance monitoring (Loop A) has been found to enhance market acceptance (Loop E), which in turn attracts more market entrants and enables scalability dynamics (Loop B). This suggests that interventions should be designed to amplify these positive feedback loops whilst mitigating the negative ones.

Cross-sectoral collaboration has been identified as a critical factor for successful implementation of these intervention pathways. The research findings indicate that closer cooperation between housing associations, construction firms, technology providers, and policymakers would facilitate the development of standardised approaches and shared knowledge. Furthermore, the transfer of knowledge on an international scale, particularly from countries such as the Netherlands where serial retrofitting has moved beyond the pilot phase, would provide valuable insights for overcoming specific barriers in the German context.

Discussion and conclusion

Serial retrofitting represents a promising approach to address Germany's building decarbonisation challenges. It offers significant potential to enhance energy efficiency and living standards whilst reducing greenhouse gas emissions. The analysis confirms its status as a transformative innovation according to the Wuppertal Institute's criteria and positions it within the diffusion phase of the MLP framework. The identification of six interdependent feedback loops provides a framework for understanding the complex dynamics driving diffusion. The analysis of barriers highlights institutional, economic, and cultural challenges that must be addressed to achieve regime reconfiguration.

Coordinated interventions across regulatory, financial and cultural domains are essential to effect transformative change. Regulations must be harmonised, innovative funding mechanisms must be introduced, and cultural shifts within the construction industry must occur. These processes must proceed in parallel to create conditions conducive to widespread adoption. As serial retrofitting continues to evolve, ongoing research and critical evaluation will be essential to ensure that its implementation advances not only environmental sustainability but also social equity and economic prosperity. The transformative potential of this approach lies not merely in its technological capabilities but in its capacity to catalyse systemic change across Germany's housing and construction sectors.

In consideration of the study's limitations, it should be noted that several limitations must be acknowledged when interpreting the findings. The reliance on expert interviews and current market analysis provides limited insight into long-term dynamics, particularly regarding economic viability and scalability. The application of the MLP framework, whilst illuminating, inherits the theoretical limitations identified by critics, particularly regarding potential technological determinism and the underemphasis of social and political factors. The study partially addresses these concerns by advocating for policy-industry interventions and acknowledging socio-political risks. The focus on multi-family housing constructed between 1950 and 1970 ensures analytical coherence but potentially limits the generalisability of findings to other building typologies or construction periods. Furthermore, the specific institutional frameworks and market structure characteristic of the German context may lead to findings that are not directly transferable to other national contexts.

The findings indicate several potential avenues for future research. First, longitudinal studies that track the evolution of serial retrofitting towards reconfiguration should provide insight into the operation of feedback loops over time and the response of barriers to policy interventions. A mixed-methods approach, integrating quantitative market data with qualitative assessments of institutional change, could be employed in these studies.

Second, research on the socio-economic dimensions of serial retrofitting is essential to understand the differential impacts across income groups and to ensure equitable access and distribution of benefits. In accordance with the results of this study, a fundamental analysis of serial retrofitting in a socio-economic context is being planned. The aim of this analysis is to examine the economic and social implications in order to further investigate its feasibility and social acceptance in Germany.

Finally, evaluations of policy instruments, incentive structures, and regulatory frameworks would guide policymakers in designing mechanisms to promote equitable implementation. Empirical studies and cross-national research would enhance understanding of the dynamics shaping serial retrofitting's transformative potential.

References

Agora Energiewende, ifok, & BPIE. (2024). *Serielle Sanierung. Effektiver Klimaschutz in Gebäuden und neue Potenziale für die Bauwirtschaft*. https://www.agora-energiewende.de/fileadmin/Projekte/2023/2023-11_DE_Serielle_Sanierung/A-EW_323_Serielle_Sanierung_WEB.pdf

BAFA – Bundesamt für Wirtschaft und Ausfuhrkontrolle. (2023). *Bundesförderung Serielles Sanieren*. Federal Office for Economic Affairs and Export Control. https://www.bafa.de/DE/Energie/Energieeffizienz/Serielles_Sanieren/serielles_sanieren_node.html

Best, B. (2019). *Energiewende und Bürgerbeteiligung. Multi-Level-Konstellationsanalysen des Beteiligungsprozesses der InnovationCity Ruhr – Modellstadt Bottrop*. Springer Fachmedien Wiesbaden GmbH.

Bögel, P. M., Augenstein, K., Levin-Keitel, M., & Upham, P. (2022). An interdisciplinary perspective on scaling in transitions. *Environmental Innovation and Societal Transitions,* 24, 170–183. https://doi.org/10.1016/j.eist.2021.12.009

BPIE – Buildings Performance Institute Europe. (2024). *The EPBD decrypted: A treasure chest of opportunities to accelerate building decarbonisation*. https://www.bpie.eu/wp-content/uploads/2024/04/082_BRIEF_The-revised-EPBD-–-decrypted_Final.pdf

Bundesregierung. (2019). *Klimaschutzprogramm 2030 beschlossen. Entlasten und investieren*. https://www.bundesregierung.de/resource/blob/974430/1679914/c8724321decefc59cca0110063409b50/2019-10-09-klima-massnahmen-data.pdf?download=1

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions. *Energy Research & Social Science,* 37, 175–190. https://doi.org/10.1016/j.erss.2017.09.015

dena – Deutsche Energie-Agentur GmbH. (2023). *Serielles Sanieren nach der Energiesprong-Idee. Tempo für klimaneutrale Gebäude*. https://www.energiesprong.de/newsroom/publikationsdetailansicht/pub/factsheet-energiesprong/
dena – Deutsche Energie-Agentur GmbH. (2024). *Serielle Sanierung. Schritt für Schritt. Wegweiser Wohnungswirtschaft*. https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2025/Serielle_Sanierung_Schritt_fuer_Schritt_Wegweiser_WW.pdf
Energiesprong International. (2023). *Energiesprong International. Marktentwicklung weltweit*. https://www.energiesprong.de/marktentwicklung-aktuell/energiesprong-international/
EnEV-online. (2020). *EnEV-Archiv – Energieeinsparverordnung für Gebäude*. https://enev-online.de/enev/
Eßmann, F., Gänßmantel, J., & Geburtig, G. (2022). *Energieeffiziente Gebäudesanierung*. Fraunhofer IRB Verlag.
EC – European Commission. (2020). *Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty*. https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1835
EU – European Union. (2023). *Maßnahmen im Themenbereich Energie. Investitionen in eine nachhaltige Energiezukunft für Europa*. https://european-union.europa.eu/priorities-and-actions/actions-topic/energy_de
Fischedick, M., Haake, H., Arnold, K., Götz, T., Hennes, L., Kaselofsky, J., Koska, T., Leipprand, A., Samadi, S., Schüwer, D., Speck, M., Suerkemper, F., Thomas, S., Venjakob, J., von Geibler, J., & Wilts, H. (2021). *Transformative Innovationen*. Wuppertal Institut für Klima, Umwelt, Energie. https://www.econstor.eu/bitstream/10419/235563/1/1761645250.pdf
Galvin, R. (2023). Policy pressure to retrofit Germany's residential buildings to higher energy efficiency standards: A cost-effective way to reduce CO_2 emissions? *Building and Environment,* 237, 110316. https://doi.org/10.1016/j.buildenv.2023.110316
Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and case-study. *Research Policy,* 31(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8
Geels, F. W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability,* 39, 187–201. https://doi.org/10.1016/j.cosust.2019.06.009
Geels, F. W. (2020). Micro-foundations of the multi-level perspective on socio-technical transitions: Developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory. *Technological Forecasting and Social Change,* 152, 119894. https://doi.org/10.1016/j.techfore.2019.119894
Gottschalk, S. (2020). Serielles Modernisieren: LEG-Quartier in Mönchengladbach wird erstes Reallabor für serielles Modernisieren im Net-Zero-Standard nach Energiesprong-Prinzip. *Wohnungswirtschaft heute,* 11. https://wordpress.wohnungswirtschaft-heute.de/wp-content/uploads/2020/10/serielles-modernisieren-LEG-Reallabor-Net-Zero-Standard.pdf
Helmrich, R., Maier, T., Padur, T., & Wolter, M. I. (2021). *Baugewerbe zwischen Klimawandel und Fachkräfteengpass*. https://res.bibb.de/vet-repository_779583
Henger, R., Runst, P., & Voigtländer, M. (2017). *Energiewende im Gebäudesektor. Handlungsempfehlungen für mehr Investition in den Klimaschutz*. Institut der deutschen Wirtschaft Köln Medien GmbH.

Hermann, L., Metzger, S., Reher, C., Steuwer, S., Boll, J. R., Broer, R., & Volt, J. (2021). *Serielle Sanierung in Europa und Deutschland*. https://www.umweltbundesamt.de/publikationen/serielle-sanierung-in-europa-deutschland

Hörnemann, M. (2023). *Energieeffizienz und Serielles Sanieren*. https://oekozentrum.nrw/energieeffizienz/serielles-sanieren/was-ist-serielles-sanieren/

Interreg. (2021). *Projekt Mustbe0 (Nordwesteuropa)*. https://www.interreg.de/INTERREG2021/DE/Projekte/GuteBeispiele/EnergieUndKlimawandel/Mustbe0/mustbe0_node.html

Königstein, T. (2024). *Ratgeber energiesparendes Bauen und Sanieren. Neutrale Informationen für mehr Energieeffizienz*. Fraunhofer IRB Verlag.

Kuckartz, U. & Rädiker, S. (2022). *Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung. Grundlagentexte Methoden.* Beltz Juventa Verlag.

Mauel, M. S., Beusker, E., & Wallbaum, H. (2024). Serielle Sanierung als transformative Innovation. Ein Schritt in Richtung urbane Nachhaltigkeit. *Transforming Cities,* 1(Kommunale Wärmewende), 28–33. https://elibrary.utb.de/doi/abs/10.5555/tc202410028?download=true

MHKBD NRW – Ministerium für Heimat, Kommunales, Bau und Digitalisierung des Landes Nordrhein-Westfalen. (2023). *Ein Baustein des Wohnraumförderprogramms 2023–2027. Förderung für Modernisierung von Wohnraum. RL MOD NRW 2023*. https://www.mhkbd.nrw/foerderprogramme/foerderung-fuer-modernisierung-von-wohnraum

ÖkoZentrum NRW. (2023). *Förderung der seriellen Sanierung über die Bundesförderung für effiziente Gebäude (BEG)*. https://oekozentrum.nrw/energieeffizienz/serielles-sanieren/beg/

Olbrich, S., & Bauknecht, D. (2024). The system building perspective for building sustainable system configurations using the German energy transition as an example. *Oxford Open Energy,* 3, oiae010. https://doi.org/10.1093/ooenergy/oiae010

Rogers, E. M., Medina, U. E., Rivera, M. A., & Wiley, C. J. (2005). Complex adaptive systems and the diffusion of innovations. *The Innovation Journal: Public Sector Innovation Journal,* 10(3), 1–25. https://innovation.cc/wp-content/uploads/2005_10_3_3_rogers_diffusion-innovation.pdf

Sebi, C., Nadel, S., Schlomann, B., & Steinbach, J. (2018). Policy strategies for achieving large long-term savings from retrofitting existing buildings. *Energy Efficiency,* 12, 89–105. https://doi.org/10.1007/s12053-018-9661-5

Schneidewind, U. (2019). *Die große Transformation. Eine Einführung in die Kunst gesellschaftlichen Wandels* (3rd ed.). Fischer Taschenbuch.

Schubert, S., Bartke, S., Becken, K., Breitmeier, M., Brozowski, F., DeTroy, S., Grimski, D., Ilvonen, O., Keßler, H., Messner, D., Meilinger, V., von Schlippenbach, U., Schröder, A., Schuberth, J., Hillebrandt, A., Lerm, M., Lützkendorf, T., & Reicher, C. (2023). *Positionspapier 02. Umwelt und Klima schützen – Wohnraum schaffen – Lebensqualität verbessern*. https://www.umweltbundesamt.de/publikationen/umwelt-klima-schuetzen-wohnraum-schaffen

Schumacher, K., Cludius, J., Liste, V., Kenkmann, T., Nissen, C., & Noka, V. (2023). *Mehrfamilienhäuser: Der blinde Fleck der sozialen Wärmewende*. https://www.rosalux.de/fileadmin/rls_uploads/pdfs/Studien/Oeko-Institut-2023-Soziale-Aspekte-Waermewende_RLS.pdf

Statistisches Bundesamt. (2022). *Gebäude und Wohnungen*.

https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Wohnen/Publikationen/Downloads-Wohnen/fortschreibung-wohnungsbestand-pdf-5312301.pdf?__blob=publicationFile

Thamling, N., & Rau, D. (2023). *Hintergrundpapier zur Gebäudestrategie Klimaneutralität 2045*. https://www.bundesregierung.de/breg-de/suche/hintergrundpapier-zur-gebaeudestrategie-klimaneutralitaet-2045-2171310

Umweltbundesamt. (2023). *Treibhausgasminderungsziele Deutschlands*. https://www.umweltbundesamt.de/daten/klima/treibhausgasminderungsziele-deutschlands#internationale-vereinbarungen-weisen-den-weg

UNFCCC – United Nations Climate Change. (2023). *The Paris Agreement*. https://unfccc.int/process-and-meetings/the-paris-agreement

Vargo, S. L., Akaka, M. A., & Wieland, H. (2020). Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. *Journal of Business Research,* 116, 526–534. https://doi.org/10.1016/j.jbusres.2020.01.038

Victor, D. G., Geels, F. W., & Sharpe, S. (2019). *Accelerating the low carbon transition. The case for a stronger, more targeted and coordinated international action*. https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf

Yildiz, Ö., Maraj, B., Steidle, D., Altner, M., Steuwer, S., Broer, R., Pöhlker, T., Korte, C., Ferrarelli, L., Ahlers, M., & Neumüller, T. (2022). *Marktstudie und Handlungsoptionen zur seriellen Sanierung*. Ifok GmbH. https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/bafa-serielle-sanierung-gesamtbericht.pdf?__blob=publicationFile&v=6