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EXPLORING LEAN PRINCIPLES IN LARGE-SCALE RENOVATION: A REVIEW OF SOCIO-ECONOMIC IMPACTS

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ABSTRACT
Large-scale renovations, as promoted by the European Union's Renovation Wave initiative, are essential for achieving energy efficiency and climate goals while delivering socio-economic benefits. Yet, such projects face considerable challenges, including high upfront costs, stakeholder fragmentation, and limited process scalability. This paper explores the socio-economic implications of large-scale renovations, emphasizing opportunities to reduce inefficiencies and improve customer value. Based on a systematic literature review and lean construction principles, the study highlights how methods such as Value Stream Mapping, Target Value Design, and Location-Based Scheduling, supported by portfolio-level planning, multiskilled teams, and coordinated crew flow, can improve process reliability, reduce waste, and enable scalable renovation strategies. The findings offer actionable insights for policymakers and practitioners aiming to align environmental objectives with social and economic value creation.

KEYWORDS
Lean construction, renovation, sustainability, socio-economic impacts.

INTRODUCTION
The built environment is one of the largest contributors to greenhouse gas emissions, with buildings accounting for 40% of energy consumption and 36% of emissions from energy use in the European Union (The European Green Deal, 2019). Achieving the EU's Green Deal target of carbon neutrality by 2050 requires addressing this sector through large-scale renovations of energy-inefficient buildings (European Commission, 2020). The Renovation Wave initiative aims to boost renovation rates, enhance energy efficiency, and reduce the carbon footprint of buildings. However, renovation rates remain low, averaging only 1% annually, far from the level required to meet climate goals.[1]

Energy renovations enhance building energy efficiency by improving the building envelope and integrating renewable energy sources. There is a significant potential for energy usage reductions in existing building stock through renovation (Fahlstedt et al., 2024). Energy renovations not only reduce emissions during a building's operational life but also help lower embodied carbon by extending the life of buildings, thereby reducing the need for new

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construction materials relative to new builds. Furthermore, these renovations can result in economic gains by reducing operational costs and increasing the overall value of the building (European Commission, 2020). However, there are challenges in renovation efforts, such as the complexity of this type of work (Prieto et al., 2024), as unlike new builds, renovations often involve uncertainty related to the condition of existing structures, which requires more flexible planning. Additionally, the required investment , the multitude of involved stakeholders, and a general lack of awareness (Friege & Chappin, 2014) can drag out the decision-making process and hinder project implementation.

Lean Construction focuses on reducing waste, improving efficiency, and enhancing collaboration across the construction value chain. Studies suggest that lean methods can significantly improve renovation outcomes by optimizing resource use and improving schedule compliance (Tetik et al., 2021). While lean has been applied in individual renovation projects, its role in scaled renovations and its broader socio-economic impacts remain underexplored.

This study examines the socio-economic impacts of large-scale energy renovations, focusing on how lean construction practices can overcome efficiency barriers and maximize benefits. It explores how energy-efficient renovations contribute to climate goals and deliver socio-economic advantages in Europe, addressing the central question: How can lean construction methodologies overcome barriers to large-scale renovation and enhance socio-economic outcomes?

The remainder of the paper is structured as follows. First, an overview of the lean construction applications on renovation projects is presented. Next, the method used for the analysis is detailed, followed by the results and discussion. Finally, the paper concludes by presenting the key insights and future directions for research.

BACKGROUND

In recent years, several studies have explored the application of lean construction principles in renovation projects, with an emphasis on improving productivity and efficiency, and on reducing waste. The work of Neve et al., (2021), for example, focused on the implementation of lean construction methods in four renovation projects, specifically examining their impact on construction labour productivity (CLP) and construction labour efficiency (CLE). Their findings revealed a strong positive correlation between the extent of lean practices used and improvements in CLE, suggesting that lean tools can significantly enhance the efficiency of renovation work.

This aligns with broader trends observed by Sahlberg et al., (2021), who also investigated lean techniques in renovation settings. They noted the challenges and opportunities of implementing takt production in renovation projects, highlighting the benefits of improving time management, reducing delays, and enhancing collaboration, particularly in projects involving repetitive tasks such as housing renovations. Johansen et al. (2021) added to this body of research by examining how lean practices improved productivity and reduced waste in renovation projects, emphasizing the value of methods like the Last Planner System (LPS) and Location-Based Scheduling (LBS) for improving workflow and reducing inefficiencies. Tetik et al., (2018) demonstrated that the average workplace utilization rate of workers improved in a case study on residential building renovation projects when a combination of material kitting and a consolidation centre was used.

However, most of these studies have focused on single-building renovation projects, with the goal of improving specific aspects of the renovation process, such as productivity, scheduling, and occurrence of waste. While the implementation of lean tools in these projects has shown promising results, the scope of these studies is limited in terms of scale. The application of lean principles to large-scale renovation, particularly at the district-level, remains relatively unexplored.

Pikas et al., (2021) addressed the potential for industrialized renovation on a larger scale, focusing on drivers and barriers of industrialized renovation of residential buildings. The study identified key technical drivers and barriers, including the importance of digitizing project documentation, integrating value chains, and overcoming challenges associated with logistics and material handling. The research highlighted the potential of lean construction to improve coordination and reduce waste in complex renovation projects, thereby enhancing efficiency. Wandahl et al. (2021) also investigated the role of lean in enhancing productivity and energy efficiency in large-scale renovation projects. Their exploratory case study of four domestic housing renovation projects demonstrated a correlation between the degree of lean implementation and construction labour productivity, with potential productivity improvements of up to 45% through the adoption of lean tools, practices, and methods and projected significant environmental impacts if scaled to the EU Renovation Wave target of 35 million housing units by 2030.

Both studies highlight process improvements, resource efficiency, and energy savings, but overlook the socio-economic factors that could support wider adoption. As climate targets grow more ambitious, understanding impacts like job creation, affordability, and social equity becomes essential. Social equity here means ensuring all communities, including disadvantaged groups, benefit equally from renovations and have a voice in planning. Bridging this gap is key to aligning technical goals with environmental, economic, and social sustainability.

RESEARCH METHOD

A systematic literature review was conducted to analyze the socio-economic impacts of large-scale renovation projects using the PRISMA methodology, as applied in previous lean construction reviews (Erazo-Rondinel et al., 2023; Melgar-Morales et al., 2024). Publications were retrieved from Scopus and the IGLC database, selected for their comprehensive collection of construction research and lean construction focus, respectively. The search, limited to English-language articles published between 2020 and 2024 to align with European climate goals (European Commission, 2019), used six keyword combinations for Scopus and three for IGLC. After removing duplicates and screening titles and abstracts, 13 articles were shortlisted for full-text review. Following further exclusions, four additional relevant articles were found through snowballing, resulting in six articles included in the final review.

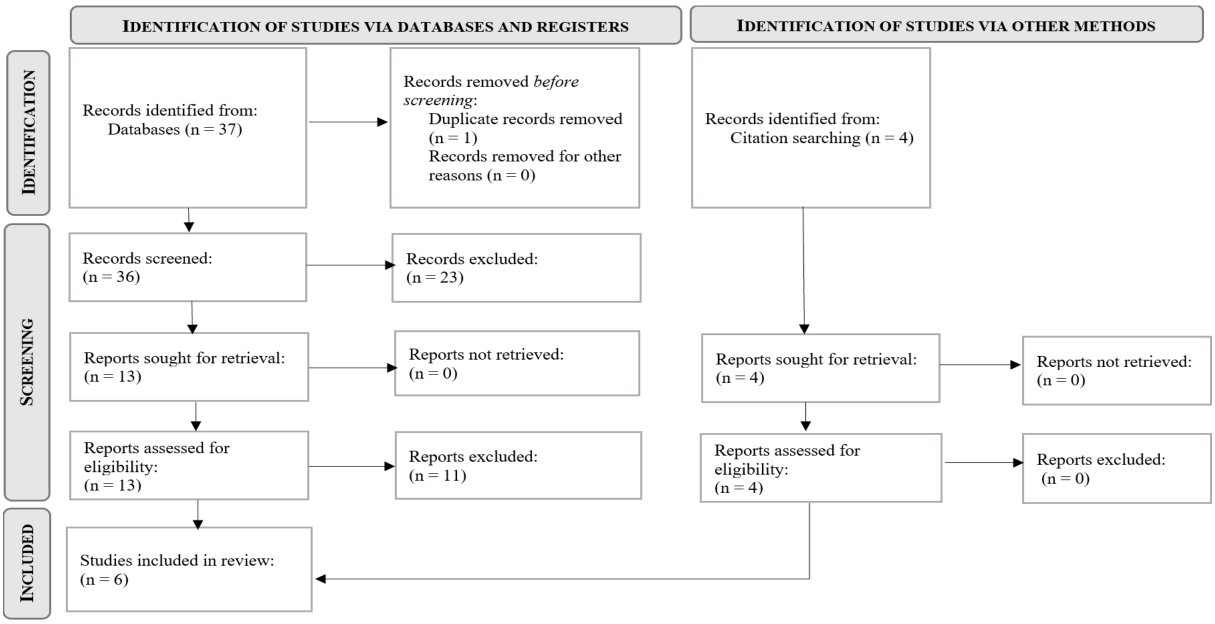

Figure 1: PRISMA flow diagram showing the selection process for articles related to socio-economic impacts of large-scale renovation projects

RESULTS AND DISCUSSION

The systematic review highlighted the difficulty of locating studies on the socio-economic impacts of large-scale renovation. Of the six papers included, only two were found via database searches, while four came from snowballing. Some keyword combinations, such as "large-scale AND renovation AND socio-economic impacts," yielded no results, indicating either limited research or poor database indexing. Snowballing proved more effective, suggesting future reviews should expand keyword strategies and include alternative databases. While many excluded studies focus on the socio-economic impacts of energy-efficient renovations (Blomqvist et al., 2022; Della Valle & Bertoldi, 2022; Ebrahimigharehbaghi et al., 2020; Niknafs et al., 2024; Pérez-Navarro et al., 2023; Streimikiene & Balezentis, 2020), few address large-scale interventions at the building group or stock level where distinct challenges and enablers emerge. Table 1 provides an overview of the key contents from the reviewed articles.

Table 1: Synthesis of the selected articles

No	Paper	Scale	Topics considered
1	Mikulić et al., (2020)	Building stock	Investment cost, GVA, number of jobs created, energy revenue, CO_2 emissions, energy savings
2	Sula et al., (2021)	Building stock	Renovation socio-economic drivers and barriers
3	Delponte et al., (2022)	City	Renovation non-energy impacts
4	Hirvonen et al., (2022)	Building stock	CO_2 emissions, lifecycle energy costs, tax revenues, number of jobs created, imported fossil fuel costs
5	Jowkar et al., (2022)	Neighbourhood	Renovation socio-economic drivers and barriers
6	Truu et al., (2024)	Neighbourhood	Socially driven collaborative renovation model

In this paper, 'large-scale renovation' refers to the broader economic, environmental, and social impacts of renovation projects beyond individual buildings, examined at the neighbourhood, city, and building stock levels. Studies at the building stock level, such as those by Mikulić et al., (2020) and Hirvonen et al., (2022), typically model economic and environmental metrics like investment costs, job creation, energy savings, CO_2 emissions, and tax revenues. These studies offer quantitative projections of the socio-economic and environmental outcomes of large-scale energy-efficient renovations. In contrast, studies at smaller scales, such as those by Jowkar et al., (2022) and Truu et al., (2024), focus on socio-economic drivers, challenges, and collaborative models within specific neighbourhoods or communities, highlighting social, institutional, and policy factors that affect renovation success.

BARRIERS

Energy-efficient renovation projects, especially when scaled up, face a range of barriers that can hinder progress. **Social barriers** are often deeply rooted in the history and emotional connections residents have with their buildings. For many long-term residents, the appearance of their homes is tied to sentimental value, which can lead to resistance against changes, especially when renovations alter the building's familiar look and feel, which complicates efforts to introduce changes that could enhance energy efficiency (Truu et al., 2024). Additionally, collaboration among residents is often a key challenge. For instance, Jowkar et al., (2022), found that 53% of surveyed homeowners in Trondheim, Norway were either uninterested in or uncertain about collaborating with other homeowners. This creates a significant hurdle, as renovation efforts in residential buildings often require the alignment and cooperation of multiple stakeholders. This lack of collaboration can result in delays or fragmented decision-making processes, hindering the successful implementation of renovation projects. A third social barrier stems from the focus of past renovations, which have primarily prioritized energy efficiency over architectural and urban design considerations (Truu et al., 2024). In many cases, if spatial quality is not considered at the outset of the renovation, it may not be feasible to address it later. For many homeowners, renovations are seen as a one-time opportunity, and once investments have been made, it may no longer be possible to improve spatial design due to the financial, logistical and technical constraints of revisiting the project. Table 2 illustrates the identified social, economic and legal barriers.

Table 2: Socio-economic barriers of large-scale renovations

Type	Barrier	Papers citing a barrier
Social	Residents' resistance to accept change	6
	Lack of resident collaboration	5
	Possible loss of spatial quality or opportunity for improvement	6
Economic	Financial constraints due to high initial investment costs	2, 3, 4, 6
	Extended payback period for investments	1, 3, 4
	Uncertainty regarding the financial viability of renovation	1
Legal	Regulatory restrictions from urban planning frameworks	6
	Decisions or legal action driven by numerous stakeholders	2, 3, 4, 6
	Lack of information regarding processes and regulations	2, 4

Economic barriers remain a major obstacle to renovation, primarily due to high upfront costs. Many residents cannot afford the initial investment, and even with loan options, they may be reluctant to take on debt for a return that takes years to materialize. As Mikulić et al., (2020) note, financial uncertainty, especially from potential energy price fluctuations, can undermine confidence in the expected savings, making renovations seem less financially viable. This is particularly discouraging for residents with limited resources or low trust in long-term benefits.

Legal barriers are primarily driven by regulatory constraints, which can vary significantly by location. Truu et al., (2024) note that urban planning frameworks often impose limitations on renovations, restricting what can and cannot be done to a building or district. These regulatory restrictions can hinder efforts to implement energy-efficient measures or change the appearance of a building, even when those changes are in line with sustainability goals. Additionally, legal decisions often involve multiple stakeholders, as various groups, including homeowners, tenants, local authorities, contractors, consultants, must agree on the course of action. This can lead to complex negotiations and delays, especially when stakeholders have conflicting interests (Hirvonen et al., 2022; Sula et al., 2021). Finally, a lack of clear information about processes and regulations is another legal barrier. Many residents and property owners are not fully informed about the necessary steps, permits, and legal requirements for carrying out renovations. This informational gap can lead to delays, missteps, or even the abandonment of projects, as stakeholders are unsure of the legal processes involved in renovation (Hirvonen et al., 2022; Sula et al., 2021).

While not mentioned in the reviewed literature, previous building modifications can also pose **technical barriers** to large-scale renovation. In some cases, earlier interventions may create a renovation lock, limiting the feasibility of further improvements. They can also reduce the applicability of standardized renovation designs and processes across multiple buildings, complicating efforts to scale solutions efficiently.

DRIVERS

Energy-efficient renovation projects are driven by several key factors that facilitate scaling up and successful implementation. **Social drivers** play an important role in engaging the community and fostering support for renovation projects. Active citizen and community engagement, highlighted in studies by Jowkar et al. (2022) and Truu et al. (2024), has proven to be a significant factor in ensuring the long-term success of renovation projects. When residents are actively involved in the planning and decision-making processes, they are more likely to collaborate, support, and contribute to the renovation effort, leading to better outcomes for all stakeholders.

Economic drivers also significantly impact renovation efforts. Efficient site management of neighbourhood-level renovation, as discussed by Truu et al., (2024), helps optimize the use of space between buildings during construction, leading to less disruption for residents. Financial incentives, such as grants, tax reductions, cost reductions on renewable energy and improved loan terms, were identified across all selected papers as essential to making renovations financially viable for homeowners and investors. Furthermore, the introduction of innovative tools and business models, including energy performance contracting (EPC), Citizen Energy Community (CEC) and on-bill financing allows for more flexible and sustainable financial solutions, lowering upfront costs and making renovations more accessible (Delponte et al., 2022; Sula et al., 2021; Truu et al., 2024). Table 3 highlights the possible enablers for driving large-scale renovations.

Table 3: Socio-economic drivers of large-scale renovations

Type	Driver	Papers citing a driver
Social	Active citizen and community engagement	5, 6
Economic	Efficient site management	6
	Financial incentives	1, 2, 3, 4, 5, 6
	Innovative tools and business models	2, 3, 6
Legal	Policies, frameworks	2, 3, 6

Legal drivers are also crucial in enabling energy-efficient renovations, particularly through the establishment of policies and frameworks that support sustainability goals. As noted by Sula et al., 2021) and Hirvonen et al., (2022), effective policies and clear frameworks provide a structured path for implementing energy-efficient renovations, ensuring that efforts are aligned with national and EU-level climate and energy targets. A central policy framework guiding building energy efficiency across all EU member states is Directive 2024/1275, known as the Energy Performance of Buildings Directive (EPBD) (European Parliament and Council, 2024). This directive mandates the implementation of Minimum Energy Performance Standards (MEPS), ensuring that buildings meet progressively higher energy efficiency thresholds. The EPBD also drives the development of Zero Energy Districts (ZEDs) and Positive Energy Districts (PEDs), extending energy efficiency principles from individual buildings to larger urban districts. A key component of the EPBD is the requirement for Energy Performance Certificates (EPCs), which monitor and verify the energy consumption of buildings, enabling regulatory compliance and supporting renovation strategies.

BENEFITS

The benefits of energy-efficient renovations extend across social, economic, and environmental dimensions, contributing to the success of large-scale projects. **Social benefits** include the renovation process fostering a strengthened sense of community among residents (Truu et al., 2024). When communities collaborate on renovation projects, it can lead to a deeper connection between residents and a greater sense of ownership over their living spaces. Additionally, renovation projects can enhance the appeal and functionality of districts, improving both aesthetic value and practical use of space. A key social benefit is also the reduction of energy poverty (Mikulić et al., 2020), as energy-efficient renovations can lower energy consumption costs, making energy more affordable for residents, especially those in lower-income households.

Large-scale renovations offer substantial **economic benefits**. Economies of scale can reduce upfront costs for materials and labour (Truu et al., 2024), and attract larger companies, whose greater resources often result in higher-quality construction. Energy performance upgrades and aesthetic improvements increase property values, while the overall demand for materials and labour stimulates local economies and creates jobs (Delponte et al., 2022; Hirvonen et al., 2022; Mikulić et al., 2020). Renovations also generate indirect economic activity in manufacturing and professional services, supporting broader economic growth and increasing tax revenues through higher income, employment, and business activity. Improved energy efficiency leads to long-term savings by lowering heating, cooling, and electricity costs, making buildings more affordable to operate. Finally, by reducing reliance on external energy sources, these renovations enhance energy security and resilience to price fluctuations (Hirvonen et al., 2022; Mikulić et al., 2020). Table 4 provides an overview of the socio-economic benefits identified from selected articles.

Table 4: Socio-economic benefits of large-scale renovations

Type	Benefit	Papers citing a benefit
Social	Strengthened sense of community	6
	Enhanced district appeal and functionality	6
	Minimized disturbance of area and residents	6
	Reduction of energy poverty	3
	Improved health of residents	3
Economic	Reduced initial costs	6
	Higher quality of construction work	6
	Creation of new jobs	1, 3, 4
	Increased property value	1, 3
	Impact on public finances	1, 3
	Reduced operational energy costs	1, 3
	Improved energy security	1, 4

Together, these social and economic benefits provide strong incentives for scaling up energy-efficient renovations, supporting broader climate goals while improving residents' quality of life and contributing to local economic growth.

DRAWBACKS

While large-scale energy-efficient renovations offer many benefits, they also pose certain **economic drawbacks**. A key concern is reduced income for energy providers, as lower energy consumption leads to decreased demand (Mikulić et al., 2020). Some studies also suggest governments may collect less in energy-related taxes (Hirvonen et al., 2022). However, this view may overlook the broader picture: energy savings are often redirected to other expenditures, potentially offsetting tax losses through increased revenue elsewhere in the economy. Another issue is the potential need for imported labor, as domestic supply may not meet the growing demand for skilled renovation workers as highlighted by Mikulić et al., (2020). This can raise costs and create integration challenges. Still, workforce transitions, such as shifting labor from new construction to renovation, could help ease shortages. Table 5 shows the negative socio-economic impacts of large-scale renovations.

Table 5: Socio-economic drawbacks of large-scale renovations

Type	Drawback	Papers citing a drawback
Economic	Reduced income and net tax revenue	1, 4
	Reliance on imported labour	1

While these drawbacks do not outweigh the overall benefits of large-scale renovations, they underline the need for strategic planning to mitigate such economic impacts.

IMPLEMENTING LEAN TO OVERCOME BARRIERS

While large-scale renovation projects present substantial benefits, they also face barriers that limit their success. Given that the literature highlights more obstacles than enablers, it is important to explore how lean construction practices can facilitate and drive the implementation of these projects. By addressing issues like high upfront costs and coordination challenges, lean can help increase the benefits of large-scale renovations and make them more feasible.

High upfront costs

To mitigate the significant upfront costs associated with large-scale renovations, lean practices such as batch procurement of designs and materials and optimized workforce allocation for phased renovations can play a crucial role in increasing overall customer value. Framed within a Target Value Design (TVD) approach, these practices can ensure that cost-saving measures are not pursued at the expense of essential user needs (Nanda et al., 2017). TVD establishes a cost ceiling early in the project and encourages teams to design within that limit while maximizing stakeholder-defined value, making it well-suited for resource-constrained, high-stakes renovation environments.

Batch procurement of designs involves purchasing standardized renovation plans for multiple buildings, particularly in cases of similar structures, such as apartment blocks. However, previous modifications made over time can introduce unforeseen variation between buildings, limiting the direct applicability of standard designs. In such cases, early assessments supported by renovation passports or flexible design approaches, such as set-based design, can help navigate discrepancies while maintaining the benefits of batch planning. While batch procurement emphasizes early standardization, set-based design can serve as a useful buffer when variation is expected. These approaches are not inherently contradictory: in contexts where many buildings remain untouched or follow similar patterns of modification, batch design remains viable, with set-based design used to manage exceptions or adapt standardized elements where needed. Similarly, batch procurement of materials allows for cost savings and consistency across sites but requires upfront clarity on building conditions to avoid waste or mismatches. By addressing these challenges proactively, these practices can still reduce costs and improve material flow, ultimately enhancing the value delivered to property owners and residents.

Optimized workforce allocation through Location-Based Scheduling (LBS) and Takt-Time Planning (TTP) enables phased renovations, where a shared workforce is deployed across multiple buildings. LBS assigns crews by physical location to reduce downtime, while TTP organizes work around consistent time intervals to maintain steady progress. This coordinated approach keeps the workforce engaged, boosts productivity, and minimizes labor inefficiencies

(Johansen et al., 2021; Sahlberg et al., 2021). These methods are particularly effective when supported by portfolio-level planning, in which projects are arranged as a continuous flow rather than isolated events. While this deviates from traditional one-piece flow, minimizing work-in-progress within a single unit, its logic is preserved through standardized sequencing and uninterrupted workflow across similar buildings. The Portfolio/Process/Operations (PPO) model illustrates how maintaining crew continuity across projects improves coordination, enables process standardization, and fosters continuous improvement (Korb et al., 2017). Multiskilling supports this by allowing tradespeople to perform a broader range of tasks, reducing delays tied to specialized crew handovers (Korb et al., 2019). Together, these strategies build team cohesion and adaptability, reinforcing learning, enabling more reliable scheduling, and ultimately shortening renovation timelines while lowering costs.

Stakeholder collaboration and knowledge sharing

Integrated Project Delivery (IPD) emphasizes early involvement, mutual trust, and shared goals, making it well-suited for complex renovations. By involving residents, designers, contractors, and authorities early on, IPD helps reduce fragmentation and later conflicts. However, barriers like limited familiarity and stakeholder distrust still impede adoption (Aapaoja et al., 2012). Target Value Design (TVD) can help build trust by promoting transparency and shared responsibility from the start. TVD has been shown to strengthen alignment, particularly in owners, by grounding decisions in a shared understanding of project value (Nanda et al., 2017). To translate these values into practice, Value Stream Mapping (VSM) can visualize the renovation lifecycle and engage a broader set of stakeholders, including residents (Björnfot et al., 2011). While TVD aligns strategic expectations, VSM communicates how value flows through each stage. VSM workshops at the neighbourhood level could help identify inefficiencies, clarify roles, and optimize collaboration. Paired with Big Room sessions, this fosters transparency and shared accountability, making renovations more inclusive and aligned with community needs.

The Last Planner System (LPS) further supports stakeholder coordination by improving communication and clarity, especially for residents (Kemmer et al., 2016). Clearly communicating milestones reduces delays caused by missed signatures, permits or short notice periods. Ji Koutei Kanketsu (JKK), a Toyota-inspired principle, complements LPS by promoting clarity in handovers and reinforcing upstream–downstream accountability (Nguyen et al., 2021). In the context of renovation, this would ensure that residents, contractors, and planners are aligned on requirements before each phase begins, helping to reduce misunderstandings and delays. JKK's principle of treating coworkers as internal customers also reinforces the importance of reliable handovers, which is particularly critical in large-scale renovations, where tasks can be more interdependent than in single-building projects.

Challenges in preserving or enhancing spatial quality during renovation

Continuous improvement plays a vital role in enhancing the quality of both residential buildings and shared neighbourhood spaces. Drawing from industrial quality cycle, which emphasize iterative planning, execution, and evaluation, a similar approach could be applied to renovation projects. As demonstrated in construction, a structured methodology can be implemented to define objectives, tasks, and responsibilities, ensuring high standards are met across all phases (del Solar Serrano et al., 2020). At the neighbourhood level, this continuous improvement approach can address the challenges of large-scale renovations, such as maintaining spatial functionality and enhancing shared spaces between buildings. By involving residents in iterative design workshops and feedback sessions, they can contribute not only to decisions about their individual homes but also to the development of communal areas such as pedestrian pathways and recreational spaces. This participatory and incremental method fosters both quality and shared ownership, ensuring that the result reflects the community's evolving needs and preferences.

CONCLUSIONS

Large-scale renovation projects hold significant potential for addressing the environmental challenges posed by Europe's aging and energy-inefficient building stock. These projects can improve energy performance, reduce operational costs, and contribute to broader climate goals. However, barriers such as high upfront costs and coordination issues remain significant obstacles.

While lean practices have primarily been explored in single-building contexts, this paper demonstrates their potential for large-scale renovations. Practices like TVD, batch procurement, and LBS help mitigate high upfront costs, optimize workforce allocation, and improve material flow. TTP ensures work progresses efficiently, while VSM and LPS enhance stakeholder collaboration and transparency, improving coordination and reducing delays. IPD promotes early involvement and mutual trust, addressing fragmentation. The PPO model and multiskilled teams support continuous improvement and workforce flexibility, ensuring smoother workflows and reducing delays.

By integrating these lean practices, large-scale renovation projects can become more efficient, cost-effective, and socially responsive. As Europe strives to meet its climate and renovation targets, adopting lean methods could unlock the full potential of large-scale renovation strategies. Future research could build on these findings through primary data collection to explore the socio-economic impacts in greater depth.

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REFERENCES

Aapaoja, A., Malvalehto, J., Herrala, M., Pekuri, A. & Haapasalo, H. 2012. The Level of Stakeholder Integration - Sunnyvale Case, *20th Annual Conference of the International Group for Lean Construction.*

Björnfot, A., Bildsten, L., Erikshammar, J., Haller, M., & Simonsson, P. (2011, July). Lessons learned from successful value stream mapping (VSM). In *19th Annual Conference of the International Group For Lean Construction*.

Blomqvist, S., Glad, W., & Rohdin, P. (2022). Ten years of energy efficiency—Exploring the progress of barriers and drivers in the Swedish residential and services sector. *Energy Reports*. https://doi.org/10.1016/j.egyr.2022.10.439

del Solar Serrano, P., del Río Merino, M., & Villoria Sáez, P. (2020). Methodology for Continuous Improvement Projects in Housing Constructions. *Buildings*, 10(11), Article 11. https://doi.org/10.3390/buildings10110199

Della Valle, N., & Bertoldi, P. (2022). Promoting Energy Efficiency: Barriers, Societal Needs and Policies. *Frontiers in Energy Research*, *9*. https://doi.org/10.3389/fenrg.2021.804091

Delponte, I., Bianco, V., & Costa, V. (2022). The Role of Non-Energy Impact Assessment in Boosting Energy Efficiency and Urban Regeneration Projects: The RenOnBill Project and Experiences from Liguria Region. *Energies*, *15*(11), Article 11. https://doi.org/10.3390/en15114093

Ebrahimigharehbaghi, S., Qian, Q. K., Meijer, F. M., & Visscher, H. J. (2020). Transaction costs as a barrier in the renovation decision-making process: A study of homeowners in the Netherlands. *Energy and Buildings*, *215*, 109849. https://doi.org/10.1016/j.enbuild.2020.109849

Erazo-Rondinel, A. A., Ccoyllar, I. M., & Huaccha, A. (2023). A Study of the Benefits of Lean Construction During the Pandemic: The Case of Peru. 1350–1359. https://doi.org/10.24928/2023/0219

European Parliament. (2024). *Directive—EU - 2024/1275—EN - EUR-Lex*. https://eur-lex.europa.eu/eli/dir/2024/1275/oj/eng

Fahlstedt, O., Ramesh, R., Hamdy, M., Temeljotov-Salaj, A., Rasmussen, F. N., & Bohne, R. A. (2024). Building renovation plan - introducing energy and cost into the managerial perspectives: A case study. *Energy and Buildings*, *310*, 114080. https://doi.org/10.1016/j.enbuild.2024.114080

Friege, J., & Chappin, E. (2014). Modelling decisions on energy-efficient renovations: A review. *Renewable and Sustainable Energy Reviews*, *39*, 196–208. https://doi.org/10.1016/j.rser.2014.07.091

Hirvonen, J., Saari, A., Jokisalo, J., & Kosonen, R. (2022). Socio-economic impacts of large-scale deep energy retrofits in Finnish apartment buildings. *Journal of Cleaner Production*, *368*, 133187. https://doi.org/10.1016/j.jclepro.2022.133187

Johansen, P., Christensen, S., Neve, H. H., & Wandahl, S. (2021). Lean Renovation – a Case Study of Productivity, Flow, and Time Improvements. *Proc. 29th Annual Conference of the International Group for Lean Construction (IGLC)* 839–848. https://doi.org/10.24928/2021/0150

Jowkar, M., Temeljotov-Salaj, A., Lindkvist, C. M., & Støre-Valen, M. (2022). Sustainable building renovation in residential buildings: Barriers and potential motivations in Norwegian culture. *Construction Management and Economics*, *40*(3), 161–172. https://doi.org/10.1080/01446193.2022.2027485

Kemmer, S., Biotto, C., Chaves, F., Koskela, L., & Fazenda, T. (2016). Implementing Last Planner in the Context of Social Housing Retrofit, *24th Annual Conference of the International Group for Lean Construction*.

Korb, S., Sacks, R., & Alhava, O. (2017). A Portfolio/Process/Operations (PPO) Analysis of a Meta-Project Production System in Renovation Projects, *25th Annual Conference of the International Group for Lean Construction.* https://doi.org/10.24928/2017/0322

Korb, S., Telyas, A., Sacks, R., & Duka, A. (2019). Evaluating Multiskilling in Residential Construction Projects Using Regional Industry Simulation, Proc, *27th Annual Conference of the International Group for Lean Construction* 1229–1240. https://doi.org/10.24928/2019/0182

Melgar-Morales, M. A., Erazo-Rondinel, A. A., Abregu-Gonzales, J. J., Nuñez-Quispe, R. R., Cruz-Huamani, C. I., & Ccoyllar-Escobar, I. M. (2024). A Review of Poka Yoke in Construction Projects: Classification, Benefits and Barriers. *Proceedings of the 32nd Annual Conference of the International Group for Lean Construction (IGLC 32)*, 214-225. https://doi.org/10.24928/2024/0152

Mikulić, D., Slijepčević, S., & Buturac, G. (2020). Energy renovation of multi apartment buildings: Contributions to economy and climate changes. *Energy and Buildings*, *224*, 110247. https://doi.org/10.1016/j.enbuild.2020.110247

Nanda, U., K. Rybkowski, Z., Pati, S., & Nejati, A. (2017). A Value Analysis of Lean Processes in Target Value Design and Integrated Project Delivery: Stakeholder Perception. *HERD*, 10(3), 99–115. https://doi.org/10.1177/1937586716670148

Neve, H. H., Lerche, J., & Wandahl, S. (2021). Combining Lean Methods to Improve Construction Labour Efficiency in Renovation Projects, *Proc. 29th Annual Conference of* *the International Group for Lean Construction*, 647-656. https://doi.org/10.24928/2021/0107

Nguyen, Q. A., Koskela, L., Potter, D., Tezel, A., Pedo, B. & Tzortzopoulos, P. 2021. Application of Ji Koutei Kanketsu in Highways Design Process Improvement, *Proc. 29th Annual Conference of the International Group for Lean Construction*, 623-633. doi.org/10.24928/2021/0186

Niknafs, P., Holmqvist, G., Thollander, P., & Rohdin, P. (2024). Energy renovation of Swedish single-family houses—A survey of barriers, drivers, and green loans. *Frontiers in Energy Research*, *12*. https://doi.org/10.3389/fenrg.2024.1480098

Pérez-Navarro, J., Bueso, M. C., & Vázquez, G. (2023). Drivers of and Barriers to Energy Renovation in Residential Buildings in Spain—The Challenge of Next Generation EU Funds for Existing Buildings. *Buildings*, *13*(7), Article 7. https://doi.org/10.3390/buildings13071817

Pikas, E., Seppänen, O., Koskela, L., & Peltokorpi, A. (2021). Challenges in Industrialized Renovation of Apartment Buildings, *Proc. 29th Annual Conference of the International Group for Lean Construction*, 985-994.. https://doi.org/10.24928/2021/0155

Prieto, A., Armijos-Moya, T., & Konstantinou, T. (2024). Renovation process challenges and barriers: Addressing the communication and coordination bottlenecks in the zero-energy building renovation workflow in European residential buildings. *Architectural Science Review*, *67*(3), 205–217. https://doi.org/10.1080/00038628.2023.2214520

Renovation Wave. (2020). European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1835

Sahlberg, J., Lehtovaara, J., & Seppänen, O. (2021). Implementing Takt Production in Renovation Projects. *Proc. 29th Annual Conference of the International Group for Lean Construction*, 677-686. https://doi.org/10.24928/2021/0113

Streimikiene, D., & Balezentis, T. (2020). Willingness to Pay for Renovation of Multi-Flat Buildings and to Share the Costs of Renovation. *Energies*, *13*(11), Article 11. https://doi.org/10.3390/en13112721

Sula, M., Mahapatra, K., & Mainali, B. (2021). Barriers and drivers for scaling-up energy renovations, *2021 ECEEE Summer Study on Energy Efficiency: A New Reality?, 637-647.*

Tetik, M., Peltokorpi, A., Holmström, J., & Seppänen, O. (2018). Impacts of an assembly kit logistic solution in renovation projects: A multiple case study with camera-based measurement, *25th International EurOMA Conference.*

Tetik, M., Peltokorpi, A., Seppänen, O., Leväniemi, M., & Holmström, J. (2021). Kitting Logistics Solution for Improving On-Site Work Performance in Construction Projects. *Journal of Construction Engineering and Management*, *147*(1), 05020020. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001921

The European Green Deal—European Commission. (2019). https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

Truu, M., Lihtmaa, L., & Niinemägi, M. (2024). Revitalizing Modernist Districts: Neighbourhood Level Mass-Renovation with SOFTacademy Project | Journal of Sustainable Architecture and Civil Engineering. *Journal of Sustainable Architecture and Civil Engineering*. https://doi.org/10.5755/j01.sace.34.1.35646

Wandahl, Perez, Salling, Neve, Lerche, & Petersen. (2021). The Impact of Construction Labour Productivity on the Renovation Wave. *Construction Economics and Building*, *21*(3). https://doi.org/10.5130/AJCEB.v21i3.7688