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Research Article/ Review Article/ Perspective Article (Remove where relevant)

Prefabricated Refurbishment in Solid Construction in Germany: Systematic Evaluation of Opportunities and Challenges

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Germany aims to achieve a climate-neutral building stock by 2050, yet many existing residential buildings require substantial refurbishment. A promising approach to speed up these processes is prefabricated refurbishment. While prefabricated timber solutions have gained traction due to their speed and energy performance, their limitations in fire safety and moisture resistance remain critical. Solid construction systems—such as concrete or masonry—offer advantages in durability, fire resistance, and structural performance, but are rarely used in prefabricated refurbishment. This study explores the potential of solid prefabrication systems for large-scale refurbishment in Germany. A literature review established the current state of serial refurbishment and highlighted differences between timber and solid construction. To address the practical implementation gap, an expert workshop was conducted to develop a process framework specific to solid prefabrication refurbishment. Ten semi-structured interviews then validated and refined this framework, capturing expert insights on technical, logistical, and regulatory challenges. Thematic analysis distilled key benefits and barriers from the collected data. Findings indicate that using solid prefabrication for refurbishment enables durability, sound insulation, and fire safety, ensuring long-term cost-effectiveness. Digital planning tools can further streamline implementation. Financial incentives from the government play a critical role in adoption. Although promising, this study remains conceptual: no pilot project has been conducted to validate real-world feasibility or quantify performance gains. Despite this limitation, the study provides actionable insights for policymakers, designers, and contractors aiming to scale up resilient, high-performance refurbishment strategies. Solid prefabrication may play a vital role in meeting Germany's ambitious climate targets.

Keywords: prefabrication, prefabricated refurbishment, serial refurbishment, solid construction

Highlights

- Prefabricated refurbishment is gaining traction in Germany. Experience is richer in timber than in massive construction. Current momentum is largely subsidy-driven; without public support, projects are often not yet profitable for investors.
- Standardized workflows and prefabrication accelerate on-site execution. Success hinges on a product mindset, a clear portfolio strategy on the owner side, and repeated use of standard components.
- Process flows between timber and solid construction are broadly similar across materials; differences mainly concern factors like element weight and logistics. Massive construction stands out for durability, robustness, and fire safety performance.

1 Introduction

The built environment plays a central role in global efforts to increase energy and resource efficiency. In 2022, the building sector accounted for 37% of global CO_2 emissions (UNEP, 2021; GABC, 2021), underscoring the importance of energy-efficient refurbishment in achieving climate targets. This issue is especially pressing in Germany, where approximately 75% of buildings were constructed prior to the implementation of modern insulation standards (Ramesh et al., 2010),rendering them in dire need of refurbishment. Consequently, 69% of construction activity in 2020 was attributable to refurbishment projects, with the goal of achieving climate neutrality in the building sector by 2050 (Gornig et al., 2020).

A promising approach to accelerating refurbishment efforts is serial refurbishment. This approach uses industrial prefabrication to minimize on-site construction time, reduce costs and increase energy efficiency (Glicker & Broer, 2022). Although timber-based systems are currently dominant due to their ecological benefits, they have limitations, such as fire safety concerns and moisture sensitivity. Conversely, solid construction methods using concrete or masonry are less commonly employed in serial refurbishment despite being assumed to offer advantages such as greater structural capacity, improved fire resistance, and long-term durability. Nevertheless, their implementation in serial refurbishment appears limited and under-explored.

This study investigates the specific potential and challenges of serial refurbishment in solid construction to examine these assumptions in depth. The study also aims to outline an ideal process for efficient implementation. Using qualitative research design, expert interviews were conducted and analyzed using a structured content analysis approach. The interview data were categorized thematically to compare conventional and serial refurbishment processes, as well as timber and solid construction methods. The findings provide a systematic basis for broader practical application and will guide future research in this area.

2 Prefabricated Refurbishment in Germany

Serial construction differs from conventional methods primarily by shifting value creation from construction sites to controlled production environments. This shift enables higher standardization, efficiency, and quality (Diehl, 2024). In conventional refurbishment, project-specific planning often follows the "push" principle, producing components in advance. In contrast, serial refurbishment uses a "pull" approach, initiating production only after receiving an order, which reduces material waste and storage needs. This concept was originally introduced by Vrijhoef and Koskela (2005) in the context of lean construction.

In refurbishment practice, this industrialized approach uses prefabricated facades, roofs, windows, and integrated system technologies to enable rapid, minimally invasive modernization. These components are standardized and repeatable, requiring only minor adaptations to suit different types of buildings. Refurbishment processes are underpinned by digital technologies. High-precision 3D scanning and Building Information Modeling (BIM)-based workflows enable precise mapping of existing geometries and just-in-time assembly of prefabricated elements (Ecoworks, 2023). This reduces on-site time and disruption. For example, the P2Endure research project calculates the potential for saving at least 60% of energy after deep renovations with modular processes, as well as 15% in costs and 50% in time (Łukaszewska, 2018). Monteleone et al. (2025), meanwhile, demonstrated the integration of heating and ventilation into prefabricated façade modules to further reduce on-site intervention.

International initiatives underscore scalability. The Dutch Energiesprong program exemplifies how net-zero energy refurbishments can be delivered within weeks, demonstrating technical feasibility and market acceptance.

In Germany, current pilot projects primarily targeting post-war apartment buildings illustrate the dominance of timber elements. Timber construction enables thin walls, lightweight structures, and high flexibility for adaptations and densification. It also allows for diverse architectural designs. However, it requires stricter fire protection measures (Kind et al., 2022; Lattke et al., 2023; Meyer & Klotz, 2023). Nevertheless, despite their technical promise, solid construction workflows are less well-documented than timber-based solutions. This study addresses this gap by examining serial, energy-efficient refurbishment with upstream industrial prefabrication. The study uses façade elements in solid construction as a reference case to identify potential and challenges.

3 Methodology

The empirical component of this study investigates the perspectives of practitioners who have worked on prefabricated refurbishment projects executed either in timber construction or in heavy-weight masonry and concrete construction. Because empirical research on such projects, particularly those using massive construction materials, is still scarce in Germany, a qualitative research design was selected to gain a deeper understanding of perceived potentials and challenges. Data collection proceeded in two stages.

An expert workshop, structured according to the guidelines of Helferich (2014), first produced a process map for carrying out Prefabricated Refurbishment of building envelopes with heavy-weight components. This map was developed by the authors, who bring experience from both research and practice, including a manufacturer of masonry and prefabricated elements as well as general contractors. Here, first, a comparative analysis was conducted between conventional and serial refurbishment procedures to highlight key differences in planning, execution and logistics. Building on this, the study distinguishes the specific process characteristics of timber-based and solid construction approaches. The resulting model synthesizes practitioner insights into a structured sequence, providing a practical framework for future implementation as well as and subsequently informed the questions used in the following interviews.

Second, a semi-structured interview guide was developed according to the procedure recommended by Bogner et al. (2014) and was pretested to refine its wording, relevance, and structure. The guide consisted of twelve open-ended questions designed to explore key aspects of serial refurbishment in solid construction. Topics included stakeholders involved, core process steps, differences from conventional and timber-based methods, logistical and technical challenges, the economic rationale, and user acceptance. The flexible format allowed for targeted follow-up questions, ensuring both the depth of responses and their comparability. Ten experts were ultimately selected. The interview sample covered a diverse range of actors from consultancy, housing companies, construction firms, and municipal institutions. Their roles ranged from strategic to technical, ensuring a multidimensional basis for the study. Each had already participated in prefabricated refurbishment projects and possessed at least three years of professional experience in the construction industry, ensuring an adequate level of contextual knowledge. Interviews lasted between thirty and sixty minutes, were recorded, transcribed verbatim and anonymized. The transcripts were analyzed using Mayring's content-structuring qualitative content analysis, applying a deductive–inductive logic (Mayring, 2010). An initial coding frame, derived from relevant literature and preliminary discussions in expert workshop, covered the principal thematic areas, whereas newly emerging issues were added as sub-categories. The category system was continually reviewed after each interview to maintain consistency and completeness. Methodological rigor was ensured by observing the quality criteria for qualitative research formulated by Steinke (1999); this involved transparent documentation of the development of the interview guide and the sampling +procedure, collective and argument-based validation of interpretations within the author team to test plausibility and enrich the findings, and strict adherence to rule-guided procedures as prescribed in established methodological manuals.

4 Results- Findings

4.1 Ideal typical process model

Based on the empirical results of the interviews, this section presents an ideal-typical process model for prefabricated refurbishment, which advances theoretical understanding of prefabricated refurbishment with masonry workflows. Synthesizing practitioner experiences and identifying common process patterns provides a conceptual framework that supports further research, comparative analyses, and methodological standardization. The model incorporates distinctions between timber and solid construction methods to reflect material-specific process dynamics.

Figure 1 Schematic representation of the ideal-typical prefabricated refurbishment process

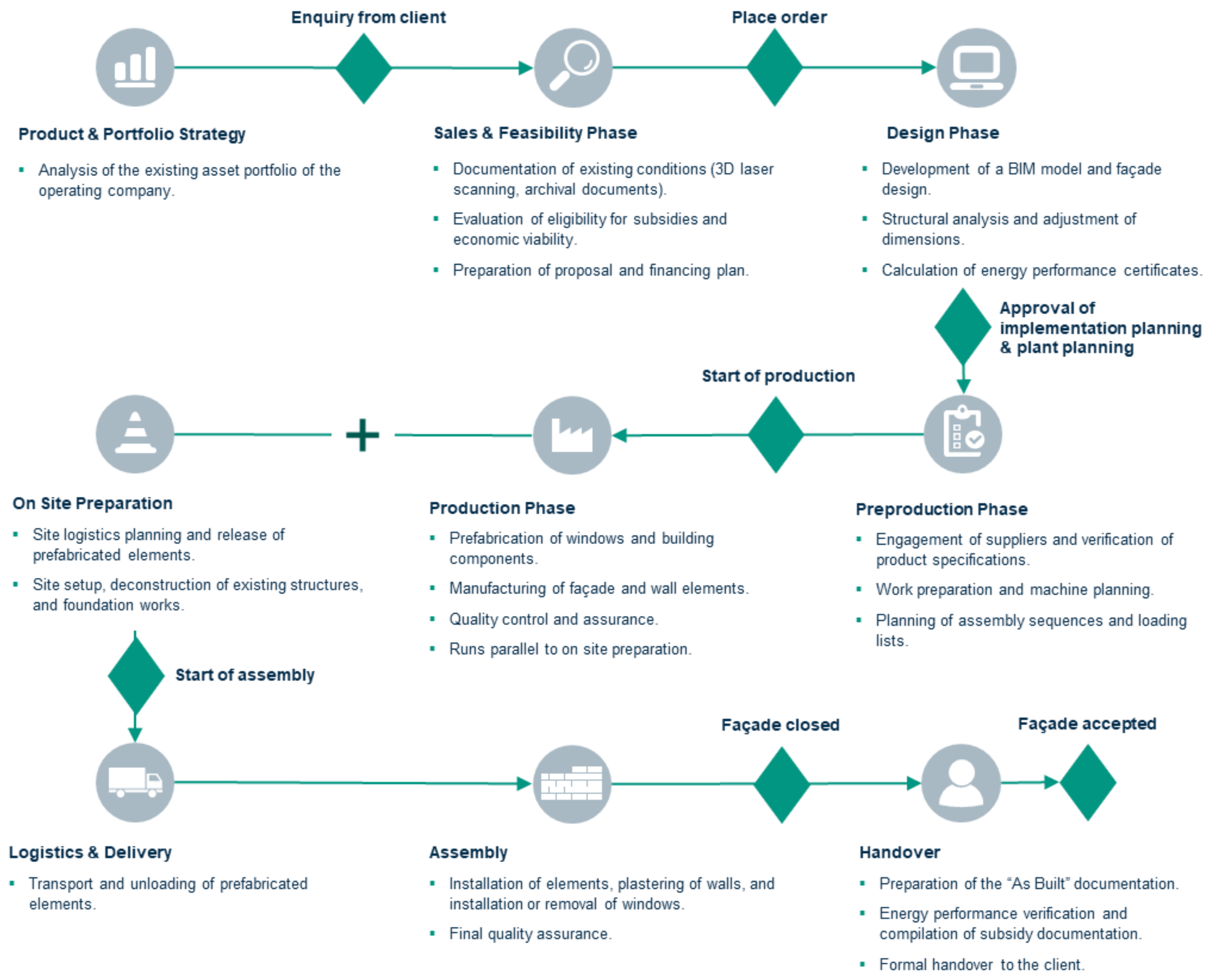

Figure 1 illustrates the sequential process of prefabricated refurbishment, from the initial client inquiry to the project handover. The process is organized into distinct phases: Product and Portfolio Strategy, Sales and Feasibility, Design, Preproduction, Production, On-Site Preparation, Logistics and Delivery, and Assembly and Handover. Production and On-Site Preparation can be done simultaneously. Each phase outlines key activities and decision points, marked as diamonds, indicate critical approvals.

Expert interviews suggest that the general process for prefabricated refurbishment is similar for timber and masonry construction compared to conventional construction. Here, serial refurbishment involves additional work, encompassing a sequence of industrialized and site-specific tasks. The process usually starts with creating a point cloud, which is sometimes a prerequisite for funding. This digital-first approach, often enabled by laser scanning or digital surveying, increases precision and standardization, allowing for faster on-site assembly. Next come consulting and feasibility studies. Next, a digital model is generated to support determining and dimensioning connections and deriving modular components in three dimensions. Subsequent steps include producing windows, calling off brick elements from suppliers, creating detailed assembly plans, and allocating machines. Prefabricated modules are delivered to the production plant, where pre-production, quality assurance, and loading, including load securing, are conducted. Next comes transport to the construction site, unloading at designated zones, and immediate preparation for installation. On-site work includes dismantling the roof, installing wall elements, assembling the new roof truss, and finally, handing over the as-built model to operations for maintenance and facility management purposes. Summarizing, in serial refurbishment a significant amount of work is being shifted into the planning and prefabrication phases.

However, using different materials introduces procedural variations and requires adapting tools and methods. In masonry-based serial refurbishment, a solid foundation and more powerful lifting equipment are necessary. Additionally, a lower degree of vertical integration is necessary since certain tasks, such as plastering, must be performed on site. Key work packages in masonry-based systems include producing brick walls with doors and windows, allowing drying time, planning and setting up the construction site, managing logistics, plastering walls, and closing wall element transitions. Masonry systems face additional challenges, such as adapting to heterogeneous existing structures, handling heavy components with special cranes, and managing storage and logistics. In contrast, timber-based construction offers shorter planning lead times, greater flexibility for short-term project starts, and easier on-site adjustments.

Table 1 compares key characteristics of timber and masonry construction across material, process, ecological, economic, and technical dimensions. In addition to the effects on the process sequence, there are clear differences in the material properties of timber and masonry construction, each presenting specific advantages and disadvantages. The low weight and high prefabrication potential of timber enable flexible and rapid assembly while maintaining a low environmental footprint. In contrast, masonry construction offers greater durability, superior acoustic and fire protection, and stronger market acceptance in Germany. Interviews indicate that aspects such as fire safety requirements, handling of heavy components, and adaptation to existing structures should be further examined in real-world projects.

Table 1 Reconciliation timber and masonry construction

Category	Criterion	Timber Construction	Masonry Construction
Material Property	Service Life	Shorter service life, higher maintenance requirements	Longer service life, robust, high durability
	Weight	Lightweight, facilitates transport and assembly	Heavy, requires stronger lifting equipment and logistics
	Thermal and Acoustic Insulation	Good insulation, limited thermal mass	High thermal mass, superior acoustic insulation
	Fire Resistance	Requires elaborate fire protection due to combustibility	Excellent fire resistance due to material characteristics
	Moisture Sensitivity	Sensitive to moisture, higher risk of damage	more resistant to moisture
Construction Process and Logistics	Construction Speed	Faster assembly, flexible for short-notice starts	Comparable assembly time, but longer planning and logistics
	Prefabrication Requirements	Shorter lead times, higher flexibility	Longer lead times, greater demand for logistics and storage
	Site Disruption	Reduced site disruption due to rapid assembly	Requires more site logistics and space
Ecology and Sustainability	Environmental Footprint	Lower embodied energy, biogenic carbon storage	Higher embodied energy, recyclable, durable
	Circular Economy	More challenging to dismantle and reuse materials	Better potential for reuse of mineral-based materials
Economic Aspects	Costs	Cost-effective in smaller markets, more adaptable	Economies of scale make it economical in larger batches
	Incentive Structures	Less complex in approvals but possibly stricter fire regulations	Less demanding fire regulations, more complex subsidies
	Market and User Acceptance	High acceptance due to ecological benefits and aesthetics	Positive acceptance due to durability, sound insulation, and market presence
Technical Challenges	Adaptation to Heterogeneous Existing Structures	More flexible and easier to adapt	More complex adaptation due to heavier materials
	Handling and Assembly	Easier handling	Heavier elements require specialized crane technology

4.2 Potentials & Challenges of prefabricated refurbishment

The following results are based on anonymized expert interviews (Interviewees A–I) analyzed using Mayring's (2010) qualitative content analysis method. The transcripts were clustered thematically to identify shared patterns and differences. Each cluster provides a concise summary that compares the different stakeholders' perspectives on key aspects of serial refurbishment, with a particular focus on deepening the potential and challenges already outlined in the ideal-typical process in Section 4.1.

4.2.1 Economic potential and cost restrictions.

Prefabricated refurbishment is primarily evaluated in financial terms. While the Interviewees agree that industrialized processes offer savings, they have significant differences of opinion regarding the prerequisites for profitability. Interviewee A emphasizes that serial refurbishment makes economic sense for large owners, as they can reduce costs and optimize processes, linking the savings to economies of scale in procurement. Interviewee D confirms this mechanism, stating that outsourcing to the factory leads to “shorter construction times, lower costs and higher quality” (Interviewee D, 2024, own translation). However, several Interviewees warn that price advantages remain limited without government support. Interviewee B openly states that “serial refurbishment ... is not economical without subsidies” (Interviewee B, 2024, own translation). In contrast, Interviewee C considers the wood-based company model to be 'viable... even without subsidies', albeit with a lower energy target.

While Interviewee B emphasized that, in terms of cost, solid construction can compete with timber systems for large quantities due to economies of scale.

Overall, the statements suggest that although economies of scale are real, they are eroded by high material costs, meaning that the design of subsidy programs acts as a mediating variable rather than a mere add-on. Summarizing the first category, long-term profitability depends on whether learning curves and market growth can offset the gradual reduction in subsidies.

4.2.2 Technical solutions and building construction

The interviewees say that solid construction has distinct advantages over timber in certain contexts. Its long material lifespan enhances durability and reduces the frequency of future interventions, contributing to favorable long-term economic performance. Its superior acoustic performance makes masonry particularly suitable for urban environments, and its strong aesthetic appeal, especially the frequent use of clinker façades in northern Germany, supports market appeal and user satisfaction. Furthermore, as interviewees B and F explained, solid construction allows for higher thermal storage mass and often more robust façade systems.

Conversely, timber-based serial construction benefits from lower weight, which simplifies transport and lifting, reduces the need for structural reinforcement, and enables faster installation with minimal disruption to occupants (Interviewees A and C**)**. However, timber's shorter lifespan compared to masonry can limit its cost-effectiveness over the building’s lifecycle, especially in projects that prioritize durability and reduced maintenance over rapid assembly.

4.2.3 Process acceleration and on-site efficiency.

A common promise of serial refurbishment is to shorten construction time in occupied buildings. Interviewee D emphasizes that “such houses... are refurbished in series after a few days” (Interviewee D, 2024, own translation) and attributes this to factory precision and reduced weather-related risks. Interviewee C adds a logistical perspective, stating that the elements are assembled directly from the truck, eliminating the need for storage space on the construction site. However, Interviewee B qualifies this optimism, as the accelerated assembly would be preceded by a longer planning phase, particularly if funding standards by the government had to be integrated.

Interviewees C and D emphasized that solid construction achieves similarly short construction times to timber construction during the assembly phase but requires a longer lead time in terms of planning and logistics, while interviewee B stated that timber construction can respond more flexibly to short-term project starts.

In summary, the focus shifts from the construction site to the planning office, enabling just-in-time deliveries and minimizing disruption to tenants. While comparable assembly speeds can be achieved with both solid and timber construction, solid construction requires longer planning and logistics lead times. In contrast, timber systems offer greater flexibility for short-term project starts, provided that planning and supply chains are equally industrialized.

4.2.4 Digital standardization and data management.

Technical standardization is both an enabler and a bottleneck. Interviewee A emphasizes that 'laser scanning ensures the accurate fit of prefabricated components' (Interviewee A, 2024), while Interviewee C confirms that adjustments are made using 3D point clouds of the existing building (Interviewee C, 2024). These digital twins form the basis of module production. However, Interviewee D warns that: “Maintaining the database is very difficult” (Interviewee D, 2024, own translation) in large portfolios. There is a tension between the need for high-resolution data acquisition and the practicality of maintaining data: precision manufacturing requires detailed information, but fragmented as-built documentation and heterogeneous building types impair data quality. Therefore, while BIM-supported workflows appear to be necessary, they are not sufficient on their own; robust information processes and interoperable standards are also crucial.

4.2.5 Regulatory and funding framework.

Institutional requirements significantly impact project feasibility. In Germany, subsidies are provided by ‘Kreditanstalt für Wiederaufbau’ (KfW) or ‘Federal Office for Economic Affairs and Export Control’ (BAFA). While KfW offers high funding rates of 40–45%, its demanding requirements may complicate financing and execution. In contrast, BAFA’s lower subsidy rate of 15% offers greater procedural flexibility and speed of implementation. Following also Interviewee A points out that “KfW funding offers 40–45%, but sets high requirements” (Interviewee A, 2024, own translation), such as fuel change requirements and costly ancillary work. Interviewee B adds an additional operational expense, stating that external energy consultants must be commissioned, which increases transaction costs. From the perspective of tenants, Interviewee D notes that the three-month deadline is legally mandated before work can commence, while Interviewee F expresses regret over the absence of incentives for non-residential buildings. Funding instruments enable projects but make them more difficult due to complex conditions and time constraints. Therefore, harmonizing the approval processes and simplifying the funding criteria seems crucial.

Interviewees B and D pointed out that solid construction prefabricated parts require fewer special fire protection solutions in approval procedures, whereas interviewee F emphasized that although timber systems are now treated equally under new building regulations, they still more frequently require project-specific fire protection certification.

4.2.6 Acceptance by tenants and stakeholders.

Overall, social acceptance is described as positive but fragile. Interviewee A observes that serial projects “are well received by tenants because they are completed more quickly” (Interviewee A, 2024, own translation). Interviewee E confirms that, once the benefits have been explained, residents “find them really good and impressive” (Interviewee E, 2024, own translation), even if there is initial uncertainty. Interviewee D summarizes the feedback as 'very good', but warns that clear communication is essential, especially if internal access is required, such as for window replacement. The positive attitude is supported by rapid implementation, reduced noise pollution and energy-saving potential, whereas unclear timetables or rental consequences can threaten confidence. Structured information campaigns are therefore a non-technical success factor.

While Interviewees E and A reported that tenants particularly appreciate the surfaces and the lower noise transmission in solid construction, Interviewees D and F described a stronger acceptance of timber construction due to its perceived ecological construction.

4.2.7 Climate and environmental imperatives.

Serial refurbishment is ultimately presented as a means of achieving climate targets. Interviewee D calculates that “in order to achieve the climate targets of the company, ... 1,500 buildings per year would have to be refurbished” (Interviewee D, 2024, own translation), emphasizing the scaling challenge. Interviewee E links the corporate strategy to achieving 'almost climate neutrality' by 2045 (Interviewee E, 2024). Interviewee F highlights operational co-benefits, noting that “we can renovate the facade during the holidays” (Interviewee F, 2024, own translation), thus avoiding relocations and grey emissions from temporary facilities.

Interviewees B and F argued that timber construction offers advantages in terms of ecological footprint due to biogenic carbon storage and lower grey energy, whereas interviewees D and E pointed to the longer service life and recyclability of mineral building materials in solid construction.

Overall, interviewees view serial refurbishment as crucial for national decarbonization due to its ability to provide high energy savings and rapid implementation. The ecological potential of serial refurbishment hinges on scaling up and lowering gray emissions from heavy components, with material choices influencing long-term environmental performance. Future research should quantify the life cycle benefits to substantiate its strategic priority.

Summarizing both, key potentials and associated risks, the interviews emphasize the importance of serial refurbishment as a strategy to accelerate climate action in the building sector. This approach offers substantial potential in terms of speed, energy efficiency, and tenant acceptance. At the same time, material-specific considerations play a critical role in implementation. Interviewees D and F emphasized that adapting to heterogeneous existing structures is more complex in solid construction due to greater weight and material rigidity. In contrast, interviewees C and B pointed to risks in timber construction stemming from higher moisture sensitivity and specific structural requirements. Interviewees A and D noted the advantages of solid construction in durability and building physics performance. Interviewees C and E emphasized the faster industrial adaptability of timber construction and its positive user perception as decisive success factors. Despite these opportunities, major challenges persist, particularly regarding cost-effectiveness without subsidies, complex approval procedures, and fragmented data management. Realizing the full potential of serial approaches will require coordinated action across policy, industry, and digital infrastructure to address these barriers and enable large-scale implementation.

5 Conclusion

This study advances the understanding of serial refurbishment by presenting a conceptual process model tailored to solid construction. It situates this model in relation to timber systems. Solid construction offers robustness, thermal mass, and well-established industrial capacities. It can achieve on-site construction times comparable to those of timber systems. However, solid construction faces challenges such as adapting to heterogeneous structures, handling heavy components, and managing sufficient storage and logistics. These challenges highlight the need for industrialized, upstream planning supported by precise digital surveys and standardized processes. In contrast, timber construction provides shorter planning lead times, greater flexibility for rapid project starts, easier on-site adjustments, and ecological benefits through biogenic carbon storage and lower embodied energy. However, timber systems may require higher life-cycle maintenance, are more sensitive to moisture, and involve project-specific regulatory considerations, particularly regarding fire safety.

Market and stakeholder perspectives further differentiate the systems. Solid construction benefits from larger industrial capacities and supports high-volume serial production. It is also valued for its durability, surface quality, and sound insulation. Conversely, timber construction can scale more rapidly in smaller markets and enjoys strong tenant acceptance due to its ecological and emotional appeal. These distinctions suggest that system choice should align strategically with project scale, market conditions, and sustainability priorities.

Overall, substantial efficiency and ecological gains in serial refurbishment depend on industrialized, cross-project planning; coordinated digital processes; and material-specific strategies. Pilot implementations are essential to validate cost-effectiveness, ecological impact, and time efficiencies. Additionally, governance decisions, such as who defines product specifications (clients or general contractors), may influence scalability. This study provides actionable guidance for practitioners and policymakers by explicitly addressing the potential, risks, and market conditions of specific systems. It emphasizes the integration of industrialized planning, digital standardization, and material-sensitive approaches to enable sustainable, efficient, and scalable refurbishment practices. Continued empirical validation and supportive policies are key to realizing the full potential of serial refurbishment across construction systems.

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Data Availability Statement
The interview transcripts collected for this study are subject to anonymization and data protection restrictions and therefore cannot be made publicly available; however, they can be accessed upon reasonable request to the authors.

Conflicts of Interest
The authors are employed at the Karlsruhe Institute of Technology (KIT) and were advised by experts from practice. As part of their work, they contacted experts in the field of serial renovation. The authors declare no other conflicts of interest.

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