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System-Level Conditions Shaping the Deployment of Wood Fibre Insulation in European Residential Construction

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Abstract

This study examines the deployment of wood fibre insulation (WFI) in residential construction through a comparative system-level analysis of Finland, Germany, and the United Kingdom. It explores how regulatory frameworks, construction systems, housing structures, and broader industrial contexts jointly shape the feasible application of WFI. The analysis combines documentary sources with expert insights to identify key structural conditions influencing WFI deployment.
The results show that WFI deployment is primarily constrained by the alignment of regulatory requirements and dominant construction systems, particularly regarding building height and fire safety classifications. Although low-rise construction offers more permissive conditions, established masonry and concrete-based practices limit broader adoption. Overall, the study demonstrates that WFI deployment is shaped by the interaction of multiple structural conditions and contributes to the literature by providing a comparative system-level perspective on the adoption of bio-based insulation materials.
Keywords: Wood fibre insulation; Bio-based construction; System-level analysis; Construction systems; Regulatory frameworks

1. Introduction

1.1 Background and Context

The transition towards low-carbon construction has become a central objective within European policy frameworks, particularly under the European Union Green Deal and related climate targets. The building sector is responsible for a significant share of global greenhouse gas emissions and material consumption, highlighting the need for more sustainable material choices and construction practices (Zhang et al., 2024; Pomponi & Moncaster 2016).
In addition to operational energy use, increasing attention has been directed towards embodied carbon emissions associated with construction materials and building products. As operational emissions decrease due to stricter energy-efficiency requirements and the decarbonisation of energy systems, the relative importance of embodied emissions is expected to increase (Röck et al., 2020; Zhang et al., 2024). Consequently, material selection has become a key consideration in efforts to reduce the overall environmental impact of buildings throughout their life cycle.
Wood-based materials have gained increasing attention due to their potential to reduce embodied emissions and contribute to carbon storage (Sathre and O'Connor, 2010; Peñaloza et al., 2016; Bourbia et al., 2023). Among these, wood fibre insulation (WFI) represents a bio-based alternative to conventional insulation materials, offering advantages in terms of renewability, circularity, carbon sequestration, and hygrothermal performance (Raja et al., 2023). In addition, WFI products are often manufactured from renewable raw materials and can contribute to the utilisation of forest industry side streams, supporting broader circular economy objectives.
Despite these potential benefits, the adoption of WFI remains uneven across countries. This variation cannot be explained solely by technical performance, but reflects broader structural conditions, including regulatory frameworks, prevailing construction systems, established industry practices, and broader industrial and construction-related contexts. Understanding these conditions is increasingly important as policymakers and industry stakeholders seek pathways for scaling up the use of bio-based construction materials in support of climate mitigation goals.

1.2 Problem Statement and Research Gap

Existing research on insulation materials has largely focused on technical performance and environmental impacts. However, less attention has been given to the system-level conditions that enable or constrain the practical deployment of bio-based materials such as WFI.

While previous studies have improved understanding of the thermal, moisture-related, environmental, and fire-performance characteristics of insulation materials, the broader context in which material choices are made has received considerably less attention. In practice, the adoption of construction materials is influenced not only by their technical properties but also by regulatory requirements, prevailing construction systems, industry conventions, market structures, and stakeholder perceptions (Gottlieb et al., 2023; Zerari et al., 2024).
Recent studies have further highlighted that the adoption of bio-based insulation materials is influenced by factors such as certification requirements, industry acceptance, skills availability, market maturity, and policy support, indicating that material deployment is shaped by broader socio-technical conditions rather than technical performance alone (Zerari et al., 2024).
Nevertheless, there remains a lack of comparative studies examining how regulatory requirements, construction traditions, industry practices, and broader industrial and construction-related structures interact to shape material choices across different national contexts. As a result, the broader conditions influencing the adoption of WFI remain insufficiently understood. Addressing this gap can improve understanding of why materials that may offer environmental benefits achieve markedly different levels of market penetration in different countries.

1.3 Objectives and Hypotheses

This study analyses the regulatory, industrial, and construction practice-related factors influencing the deployment of WFI in construction, focusing on three European countries with differing construction systems, regulatory approaches, and broader industrial contexts: Finland, Germany, and the United Kingdom.
Adopting a system-level perspective, the study examines how these broader structural conditions shape the feasible application of WFI in practice, with particular attention to the interaction between regulatory constraints and construction systems.
The study is guided by the following research question:
Under what regulatory and system-level conditions can WFI be applied, and how do these conditions influence its deployment across different national contexts?
The analytical framework adopted in this study is illustrated in Figure 1. The framework conceptualizes the deployment of WFI as a system-level outcome emerging from the interaction of multiple structural conditions.

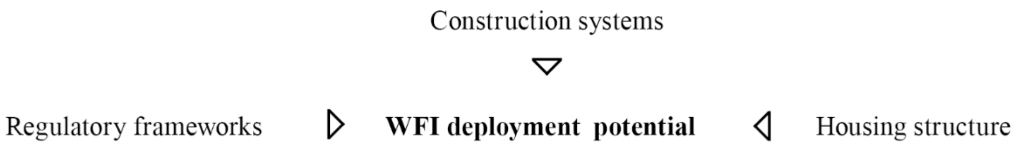

Figure 1. Analytical framework for WFI deployment, illustrating the interaction between regulatory frameworks, construction systems and housing structure.

1.4 Significance and Structure of the Paper

By focusing on the structural conditions that shape material deployment, this study contributes to the literature on bio-based construction materials by adopting a comparative system-level perspective. While previous studies have primarily examined the technical, environmental, and hygrothermal performance of insulation materials, this study investigates how regulatory frameworks, construction systems, housing structures, and industrial contexts interact to influence the practical deployment of WFI across different national settings. In doing so, it extends existing knowledge beyond material-level performance assessments and provides new insights into the broader conditions shaping material adoption in the construction sector.
In addition to its academic contribution, the study provides practical insights for policymakers, regulators, designers, and industry stakeholders seeking to increase the use of low-carbon building materials. The findings highlight the importance of considering system-level conditions when developing policies and strategies to support the wider adoption of bio-based materials.
The paper is structured as follows. Section 2 presents the materials and methods. Section 3 presents the results as a comparative synthesis of structural conditions and their implications for WFI deployment. Section 4 discusses the findings in relation to broader system-level constraints and opportunities. Finally, Section 5 concludes the paper and outlines implications for policy and practice.

2. Materials and Methods

2.1 Study Design and Setting

This study adopts a comparative qualitative case-study design focusing on Finland, Germany, and the United Kingdom. The selected countries represent differing regulatory frameworks, construction systems, housing structures, and industrial contexts relevant to the deployment of WFI, thereby providing a diverse basis for cross-country comparison.
The study applies a system-level interpretative approach to examine how these structural conditions influence the practical feasibility of WFI deployment. Rather than focusing solely on the technical characteristics of insulation materials, the analysis considers the broader regulatory, construction-related, and industrial factors that shape material adoption in practice.
The research combines documentary and statistical data with semi-structured expert interviews conducted with 15 European specialists. The interviews were used to identify key themes related to the deployment of WFI and to provide

practice-based perspectives for interpreting the documentary and statistical evidence. Together, these data sources support the development and application of the analytical framework used in the study.

2.2 Analytical Framework

The analytical framework was developed based on the themes identified through the expert interviews and subsequently refined through the review of documentary and statistical sources. The analysis is structured around three interrelated dimensions that emerged as the most influential factors affecting the deployment of WFI across the case-study countries:
(i) regulatory frameworks governing building safety and material use,
(ii) prevailing construction systems and material practices, and
(iii) housing structure, including dominant residential building types.
Together, these dimensions form the analytical framework used to compare the selected countries and to examine how structural conditions influence the applicability and deployment potential of WFI. By focusing on the interaction between these dimensions, the framework supports a system-level interpretation of material adoption beyond purely technical considerations. The overall research methodology and analytical process adopted in this study are summarised in Figure 2.

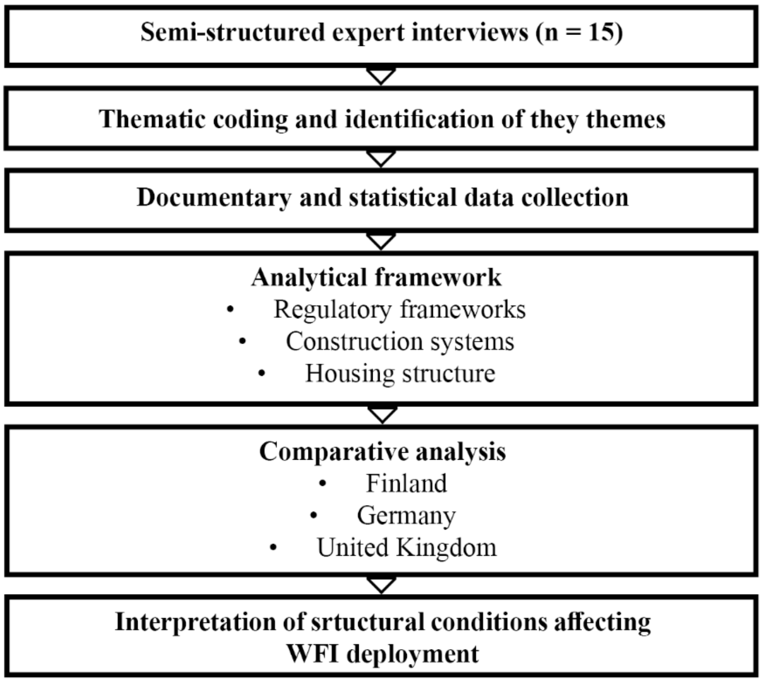

Figure 2. Research methodology and analytical process used to examine structural conditions influencing the deployment of WFI in Finland, Germany, and the United Kingdom.

2.3 Data Sources

The study draws on multiple qualitative, documentary, and statistical data sources to support the comparative analysis. These sources include:

• national building regulations and guidance documents related to fire safety and material use,
• statistical data on residential construction, housing composition, and building completion volumes,
• technical and industry-related documentation describing prevailing construction systems and material practices,
• data and reports related to industrial context, forest resources, and material markets, and
• semi-structured expert interviews with 15 European practitioners and specialists in building design, regulation, fire safety, material application, and the forest-based industry.

The documentary and statistical sources were used to characterise the regulatory, construction-related, and industrial contexts of the selected countries. The expert interviews provided complementary practice-based insights to support the interpretation of documentary and statistical evidence.
The use of multiple data sources enabled methodological triangulation and supported the validation of findings through the integration of documentary, statistical, and expert evidence. This approach supports a comprehensive understanding of the structural conditions influencing WFI deployment across the case-study countries.

2.4 Procedures and Protocols

The research process was conducted in five stages.
First, semi-structured expert interviews were conducted with 15 European specialists. The interview material was subsequently coded and analysed thematically to identify recurring themes related to regulatory frameworks, construction practices, housing structures, and broader industrial context. These themes informed the development of the analytical framework and helped identify relevant system-level factors affecting WFI deployment.
Second, national regulatory frameworks relevant to insulation materials and fire safety were reviewed for each country to identify constraints and enabling conditions for the use of WFI.

Third, dominant construction systems and residential housing typologies were examined to understand how material choices are embedded within established building practices and building traditions.
Fourth, contextual factors related to industrial structure, forest resources, and material markets were reviewed to support the interpretation of construction systems and material adoption patterns across the case-study countries.
Fifth, the collected data were integrated within the analytical framework and synthesised through a comparative analysis of the selected countries. This process was used to identify common patterns, country-specific differences, and structural conditions influencing the deployment of WFI.

2.5 Data Analysis

The analysis followed a qualitative comparative approach. The coded interview material and documentary data were examined through the three analytical dimensions of the study: regulatory frameworks, construction systems, and housing structure.
The analysis focused on identifying how these structural conditions interacted and influenced the applicability and deployment potential of WFI within each national context. Comparisons between the case-study countries were used to identify both shared patterns and context-specific differences.
The findings are presented as an interpretative synthesis of structural conditions and their interactions rather than as outputs of a quantitative modelling process.

3. Results

3.1 Structure of the Comparative Analysis

The results are presented as a comparative synthesis of the structural conditions influencing the deployment of WFI across Finland, Germany, and the United Kingdom. The analysis follows the analytical framework introduced in Section 2.2, examining how these conditions shape the feasible application of WFI in practice across the case-study countries.

3.2 Regulatory Frameworks

Regulatory conditions emerge as a central factor shaping the feasible application of WFI, particularly through fire safety requirements and material classifications. As one interviewee noted,“fire safety regulations are the only factor that can fully prevent the use of WFI.”
In Finland, regulatory conditions for insulation materials are structured around a fire classification system (P0–P3), which defines the acceptable use of combustible materials in relation to building type and height. This system is established in the Ministry of the Environment Decree on Fire Safety of Buildings (848/2017), which sets the framework for material use in different building categories. In practice, this creates a clear distinction between low-rise and multi-storey residential construction (Ministry of the Environment, 2017).
In this system, combustible insulation materials are generally permitted in P3 buildings, which in practice primarily comprise detached and row housing. In P2 buildings, their use is more restricted and typically limited to lower-rise residential buildings, such as apartment buildings up to two storeys. In P1 buildings, the use of higher-performance combustible insulation materials (e.g. Euroclass B) may be permitted under specific conditions, provided that the load-bearing structure maintains structural integrity in a fire situation. In addition, the P0 category allows for project-specific, performance-based fire safety design, where material use is assessed based on the assumed fire development of the building. However, according to expert interviews, this approach is rarely adopted in practice, as in its current form, it tends to increase both project costs and perceived uncertainties.
As a result, the deployment of WFI in Finland is largely concentrated in low-rise construction and selected building elements, whereas its application in multi-storey façades remains limited. This pattern reflects the regulatory structure rather than purely technical or market-driven factors.
In Germany, regulatory conditions are structured around building classes (Gebäudeklassen 1–5) that are closely linked to building height, with fire safety requirements generally becoming stricter as height increases. The system is primarily defined through the Model Building Code (Musterbauordnung, MBO), which serves as a reference framework, while binding regulations are enacted at the federal state level through the respective Landesbauordnungen.
In lower building classes, combustible insulation materials may be used under defined conditions. As building height increases, fire safety requirements become more demanding, and the use of combustible materials depends increasingly on the specific construction system, technical approvals, and project-specific fire safety design. For timber-based systems in particular, these conditions are further specified through guidelines such as the Model Timber Construction Directive (MHolzBauRL).
At the same time, the regulatory framework is implemented at the federal state level, which may lead to differences in interpretation and application across regions. This can increase complexity for designers and developers and may hinder the broader uptake of less conventional materials such as WFI.
As a result, the applicability of WFI in Germany varies across building segments, with more straightforward use in low-rise contexts and more constrained conditions in taller buildings.
In the United Kingdom, regulatory conditions for external wall materials are closely linked to building height, creating a threshold-based framework that differentiates between low-rise and taller residential buildings. The primary regulatory guidance is set out in HM Government’s Approved Document B, which establishes more stringent expectations for materials used in buildings above defined height limits (HM Government, 2019).
In practice, this results in a relatively permissive environment for material choices in low-rise construction in regulatory terms, where combustible insulation materials can be applied with fewer constraints. In contrast, taller buildings are subject to significantly stricter requirements, particularly for façade systems, where non-combustible solutions are generally expected in practice.

In addition to formal regulation, requirements set by insurers can influence material selection. Insurance providers may perceive certain construction materials and systems as carrying elevated fire or moisture-related risks, which can result in more conservative design choices than those strictly required by regulation (Irshaid et al., 2024).
As a result, the applicability of WFI in the United Kingdom is shaped primarily by height-based regulatory thresholds, with additional constraints emerging from insurers' requirements. While low-rise construction offers a comparatively flexible context for its use, the transition to mid- and high-rise buildings introduces conditions that significantly narrow its practical application.
Across all three countries, WFI is not explicitly prohibited, but its use is effectively constrained to specific building types and heights. This reflects a regulatory logic in which material classifications play a central role in defining the acceptable use of combustible materials in relation to building height and fire safety requirements. As one expert noted, "material classifications do not fully reflect how WFI behaves in actual building assemblies."
Building on this, several experts suggested that in certain construction assemblies, the use of WFI could be justified even in taller buildings when appropriately designed and protected. As one interviewee argued, "structural timber classified as Euroclass D can be used, so why should insulation not be allowed when it is similarly protected, for example with gypsum boards?"
This highlights a potential inconsistency within current regulatory approaches, where structural timber elements may be permitted when adequately protected, while combustible insulation materials are restricted within the same assembly layers. This suggests that regulatory frameworks may not always fully account for the fire performance of complete building systems, but instead rely on simplified material classifications.

3.3 Construction Systems, Housing Structure, and Material Practices

Prevailing construction systems play a key role in determining how WFI can be integrated into building design.
In Finland, construction practices are strongly differentiated between low-rise and multi-storey residential buildings (Ilgin et al., 2024). Timber-based systems are widely used in detached and row housing, where wall assemblies are typically based on timber frame structures with insulation integrated within the load-bearing frame. This configuration provides a structurally compatible context for WFI and can support vapour-permeable assemblies when combined with appropriate material layers (de Serres-Lafontaine et al., 2024; Roels & Tijskens, 2023). Finland's extensive and geographically widespread forest resources and long-established forest-based industry provide a strong material and industrial basis for timber construction, reinforcing the use of timber-based systems in low-rise housing.
In contrast, multi-storey residential construction is predominantly based on concrete structural systems, where façade solutions are typically developed around non-combustible, mineral-based insulation. Multi-storey residential buildings account for approximately 72% of annual dwelling completions, while detached and row houses comprise around 28%. In terms of building volume, the distribution is more balanced, with multi-storey buildings representing approximately 54% and low-rise buildings about 46% of total new residential construction (Statistics Finland, 2025).
This means that a substantial share of construction volume is realised in low-rise buildings where WFI is structurally compatible, while a slightly larger share remains associated with multi-storey buildings where established material solutions limit its application. As a result, WFI deployment is concentrated in a significant but not dominant segment of construction. At the same time, differences between building elements are evident: bio-based insulation materials are more commonly used in roof structures, whereas their use in external walls remains limited.
Germany presents a heterogeneous construction landscape in which masonry, concrete, and timber systems coexist. Masonry-based construction remains the dominant approach in residential building, accounting for approximately 46% of completed buildings, while concrete-based systems represent about 30% and timber construction around 23% (Destatis, 2025a; Mergel et al, 2022). While these shares reflect the overall sector, low-rise housing also exhibits a diverse material distribution, in contrast to the predominantly timber-based Finnish low-rise context.
This diversity is also reflected in the structure of the forest-based industry, which is large and regionally distributed across the country. Although the German market offers WFI products applicable across different construction systems, including masonry-based solutions, their use remains relatively limited and influenced by prevailing design approaches.
Approximately 63% of residential construction volume in Germany is concentrated in one- to two-storey buildings, while buildings with three or more storeys account for about 37% (Destatis, 2025b). Timber construction remains primarily associated with low-rise housing, whereas multi-storey buildings are still largely realised using masonry and concrete systems. As a result, WFI deployment varies across building segments and is shaped by the interaction between construction practices, building height, and construction volume rather than by technical feasibility alone.
In the United Kingdom, residential construction is characterised by a strong emphasis on low-rise housing, where masonry-based systems dominate. Timber-frame construction is also present, but its use varies regionally and is more common in areas such as Scotland and parts of England (Mayouf, 2022). This variation is partly linked to the structure of the forest-based industry, which is more limited in scale and geographically concentrated, particularly in Scotland (Forest Research, 2025; ONS, 2025). As a result, timber construction is more common in forest-rich regions, whereas in much of England construction practices rely more heavily on imported materials and established masonry-based systems.
External walls are typically constructed as cavity wall systems, which have become standard in residential building, and insulation choices are closely tied to these established practices. Although the predominance of low-rise housing could, in principle, provide favourable conditions for WFI, the dominance of cavity wall construction and masonry-based housing systems is generally associated with the continued use of conventional insulation materials (Mayouf, 2022).
These systems are typically designed to manage moisture through cavity-based assemblies and are commonly associated with less hygroscopic materials. As a result, the potential advantages of WFI may be less readily realised within these configurations. In multi-storey residential construction, masonry and concrete systems further reinforce the use of conventional insulation approaches.

Across all cases, material choices are shaped by established construction systems that favour familiar solutions. Even where WFI is technically permitted, its adoption remains conditioned by the structural systems within which it is applied. Timber-framed constructions and roof structures provide the most compatible context, whereas concrete and masonry-based wall systems offer fewer established application pathways. As one interviewee noted: "the continued use of conventional insulation materials is less a question of technical necessity and more a reflection of established practices and resistance to change them."

3.4 System-level synthesis of WFI deployment conditions

Table 1 summarises the key system-level conditions influencing the deployment of WFI across the case-study countries. The synthesis brings together the three analytical dimensions—regulatory frameworks, construction systems, and housing structure—to highlight both shared patterns and context-specific differences.

Table 1. Structural conditions affecting WFI deployment in the case-study countries.

Dimension	Finland	Germany	United Kingdom
Regulatory frameworks	Fire class system (P1–P3); more permissive in low-rise, stricter in multi-storey	Building class system (GK 1–5); requirements tighten with height	Height-based regulation; stricter requirements above defined thresholds (e.g. >11 m)
Construction systems	Timber common in low-rise; concrete dominates multi-storey	Mixed systems (masonry, concrete, timber)	Predominantly masonry in low-rise housing
Housing structure	High share of multi-storey residential buildings	Mixed housing structure	Predominantly low-rise housing

4. Discussion

The results demonstrate that the deployment of WFI is best understood as a system-level phenomenon emerging from the interaction of regulatory frameworks, construction systems, and housing structures, rather than from material performance alone. This interpretation is consistent with recent research on bio-based construction materials, which suggests that institutional, economic, and regulatory barriers often play a more significant role in limiting adoption than technical performance itself (Torgal, 2026). While previous studies have often focused on technical properties or environmental benefits, the findings of this study indicate that these factors are mediated by broader structural conditions that determine where and how such materials can be applied in practice. Figure 3 illustrates how different combinations of these conditions can either enable or constrain the use of WFI.

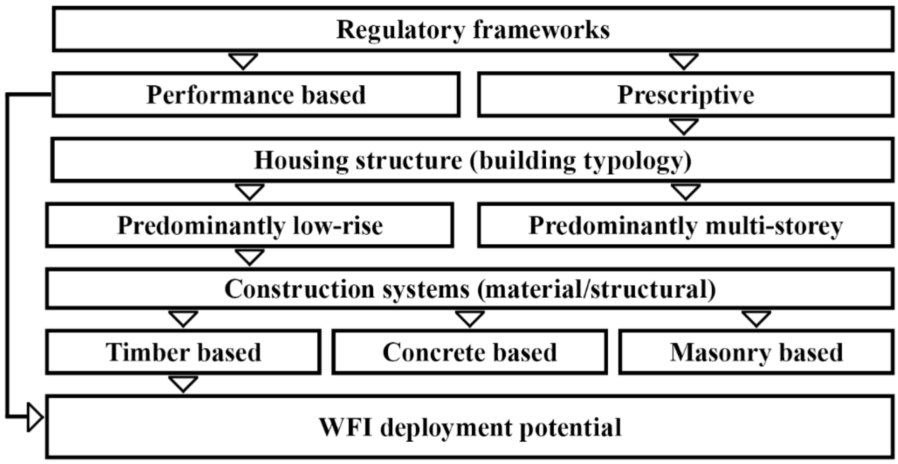

Figure 3. Structural conditions shaping WFI use.

A central observation is that regulatory frameworks, particularly those related to fire safety, define the boundaries of material permissibility. Across all case-study countries, material use is closely linked to building height and classification systems, resulting in a consistent pattern in which WFI is primarily applicable in low-rise construction, while stricter requirements limit its use in multi-storey contexts. At the same time, the findings suggest that prescriptive regulatory approaches based on material classifications do not fully account for the performance of materials within complete building assemblies. This may constrain the use of WFI beyond what would be required from a purely performance-based perspective, highlighting the potential role of more performance-oriented regulatory approaches (Järvinen et al., 2025).

However, regulatory frameworks do not operate in isolation. Their effects are closely intertwined with prevailing construction systems, which tend to favour established material solutions aligned with regulatory expectations. Timber-frame configurations provide a structurally compatible context for WFI, whereas concrete and masonry-based systems are typically associated with standardised insulation practices that are less conducive to its adoption. In this sense, regulation and construction practice form a mutually reinforcing system that stabilises existing material choices, meaning that technical feasibility alone does not necessarily translate into widespread adoption (Gottlieb et al., 2023; Carcassi et al., 2024). Similar findings have been reported for circular bio-based building materials more broadly, where adoption is influenced by interacting economic, regulatory, market, and cultural barriers rather than technical performance alone (Le et al., 2024).

Housing structure further conditions these relationships by determining the relative prevalence of building types in which WFI is technically feasible. In Finland, the high share of multi-storey construction limits overall deployment potential despite favourable conditions in timber-based low-rise housing. In Germany, the coexistence of multiple construction systems creates a more heterogeneous context in which applicability varies across segments. In the United Kingdom, the predominance of low-rise housing suggests a potentially favourable regulatory context; however, the dominance of masonry-based construction constrains the practical integration of WFI. These findings demonstrate that material substitution is shaped by established construction practices and broader socio-technical system dynamics (Geels, 2002; Gottlieb et al., 2023).

These structural conditions are also reflected in the current market penetration of WFI across the case-study countries. In Finland, WFI accounts for approximately 17% of the insulation market (Rakennustutkimus RTS, 2023). In Germany, bio-based insulation materials represent around 9% of the total insulation market, with WFI constituting the majority within this category (Künzel, 2022). In contrast, the use of bio-based insulation materials in the United Kingdom remains limited despite increasing interest in low-carbon construction, reflecting both market and industry barriers to wider adoption (Gottlieb et al., 2023; Dams et al., 2023). These differences support the interpretation that the alignment of regulatory frameworks, construction systems, and housing structure contributes to markedly different levels of WFI adoption in practice.

The results also indicate that broader industrial and resource contexts play a supporting role in shaping construction practices. Previous studies have highlighted the importance of forest-based industries in supporting the development and diffusion of bio-based products and innovations within the broader bioeconomy (D'Amato et al., 2020). The availability of forest resources, industrial capabilities, and familiarity with wood-based value chains may further contribute to the acceptance and use of wood-based construction solutions in different national contexts. This is reflected, for example, in the widespread use of timber-based systems in Finland, the more regionally distributed but still significant timber sector in Germany, and the more limited and geographically concentrated use of timber construction in the United Kingdom.

Taken together, the findings indicate that WFI deployment depends on the alignment—or misalignment—of multiple structural conditions. In particular, the compatibility between regulatory frameworks and dominant construction systems appears to be the key determinant of practical deployment, while housing structure and broader industrial context further condition how these relationships manifest in different national settings.

From a broader perspective, this study contributes to the understanding of sustainable material adoption by demonstrating that the transition towards bio-based construction materials is not solely a technological or environmental challenge, but also an institutional and systemic one (Gottlieb et al., 2023; Le et al., 2024). This suggests that increasing the use of materials such as WFI requires not only improvements in product performance and environmental assessment but also changes in the regulatory frameworks and construction system conventions that govern material selection in practice.

5. Conclusions

This study examined the deployment of wood fibre insulation (WFI) through a comparative system-level analysis of Finland, Germany, and the United Kingdom. The findings address the research question by demonstrating that the deployment of WFI is determined not by material performance alone, but by the interaction of regulatory frameworks, construction systems, housing structures, and broader industrial contexts. These system-level conditions shape both the feasibility and practical implementation of WFI across different national settings.

The results show that regulatory frameworks, particularly fire safety requirements, define the primary boundaries for WFI use. However, the influence of regulation is reinforced by dominant construction systems, which favour established material solutions and building practices. Consequently, WFI is most readily applied in timber-based low-rise construction, while its deployment is more constrained in masonry- and concrete-dominated building systems. Housing structure further influences deployment potential by determining the prevalence of building types in which WFI can be applied. In addition, broader industrial and resource contexts appear to support the use of WFI indirectly through their influence on timber construction and familiarity with wood-based materials.

The principal contribution of this study is the development and application of a comparative system-level perspective for analysing WFI deployment. While previous studies have primarily focused on the technical, environmental, and hygrothermal performance of insulation materials, this study demonstrates how regulatory frameworks, construction systems, housing structures, and industrial context interact to shape material adoption. By integrating these factors within a single analytical framework, the study extends existing knowledge on bio-based construction materials and provides new insights into the structural conditions influencing their deployment.

The findings have important implications for policy and practice. Efforts to increase the use of bio-based insulation materials should not focus solely on product performance but should also consider the regulatory approaches, construction system conventions, and industrial conditions that influence material selection in practice.

The study is limited by its qualitative and case-based approach focusing on three national contexts. Future research could build on these findings by integrating system-level analysis with quantitative modelling, exploring the role of performance-based regulatory frameworks, and examining more closely how industrial conditions influence the adoption of bio-based materials across different construction sectors.

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Conflicts of Interest
No conflicts of interest were reported by the authors.

Data Availability Statement
The anonymised interview transcripts are available from the corresponding author upon reasonable request.

Institutional Review Board Statement
Ethical review and approval were not required for this study according to local legislation and institutional requirements. All participants were informed about the study and provided their consent to participate.

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Conceptualisation: J.J.; Methodology: J.J., E.I.; Writing – original draft: J.J.; Writing – review & editing: J.J., E.I., M.K., H.H.; Visualisation: J.J.; Supervision: E.I., M.K., H.H. All authors have read and approved the final version of the manuscript.

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