Adaptability in Wood Construction: Barriers to Flexible Multi-Storey Timber Buildings

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Abstract. In an era marked by rapid and constant change, designers are challenged to create solutions that are not only sustainable but also adaptable to an ever-evolving environment. Wood, as a renewable and versatile resource, plays a pivotal role in this context. Also, timber buildings and structures are in a perpetual state of transition, and enabling these transformations is crucial for the sustainable development of our built environment.

This chapter discusses adaptability for multi-storey timber buildings, addressing the current lack of empirical data and lived experience in this area. The research aims to identify the technical barriers to adaptation of multi-storey timber buildings and which research currently addresses them.

The methodology comprises an in-depth literature review on adaptability in timber engineering and architecture and a comparative analysis of adaptability research.

The study highlights the importance of designing timber buildings with adaptability in mind, considering aspects such as acoustics, prefabrication, standardisation, span, fire safety, services and moisture planning. The findings suggest that while timber structures are designed for longevity, their potential for adaptation is often insufficient, emphasizing the need for a more holistic approach to design that includes whole-building scales, while adaptability research does not yet incorporate these timber-specific aspects.

Keywords: Multi-Storey Timber Building · Circular Economy · Wood Construction · Adaptability · Flexibility · Building Adaptation

1 Introduction

Time is a crucial factor when discussing the effectiveness of biobased materials, particularly in timber construction. To match a benchmark forest's carbon, the carbon stored in wood products plus the remaining forest carbon requires over 150 years of timber use [1]. This carbon balance exceeds by far the average lifespan of buildings. Despite being designed for durability, more than half of all buildings are demolished due to vacancy rather than technical deficiencies, indicating insufficient adaptability [2]. Current discussions about new timber buildings often focus on technological aspects, neglecting spatial-architectural and organizational-functional considerations [3]. We can close this

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gap between the carbon balance of wood and a building's obsolescence by applying circular design strategies.

MTBs offer a promising solution by fitting into both the technical and biological cycle of the Circular Economy (CE), defined as an economy that is restorative and regenerative by design [4]. While engineered wood products (EWPs) are often downcycled for energy recovery, maximizing their potential requires integration into the technical cycle through circularity design. Efforts to translate CE concepts into specific frameworks for the building industry are ongoing. Cheshire [5] outlines five design principles for applying circular economics to construction, including building in layers, designing out waste, design for disassembly (DfD), selecting materials and designing for adaptability (DfA) [6].

Although referred to as 'flexibility' in several publications [7], adaptability is defined as the capacity of a building to accommodate the evolving demands of its users and environment effectively, thus maximizing value through life [8]. An adaptable building facilitates adaptation: any work to a building over and above maintenance to change its capacity, function or performance [9]. Scenarios of change include climate change (e.g. extreme weather events or migration of pests), changes in use (e.g. office to housing) and extensions (e.g. top-up construction).

While discussions on circular timber construction often mention design for disassembly [10], experts rate it as the least effective design-based enabler for adaptability [2], as adaptability often requires layout changes and systems updates that transcend the DfD scope. Furthermore, design for circularity on a building level keeps the most carbon in place, as 14% of embodied greenhouse gas emissions can be prevented if a structure is reused as a whole instead of recycling its materials due to the associated mixed demolition waste [11].

Timber is perceived as less adaptable and more complex for alteration than other structural materials [12, 13]. However, the environmental benefits of adaptability may outweigh those of using timber alone, highlighting the need for efficient use of this renewable resource [12]. This chapter explores which physical adaptation barriers within the design process for multi-storey timber buildings contribute to this perception.

2 Methods

To investigate adaptability in timber construction, we performed an extensive literature review using Scopus and Web of Science databases in January 2025. We targeted keywords such as "adaptability," "flexibility," "timber," "wood," "design," "building," and "architecture" to uncover key design principles and their applications in multi-storey timber buildings (MTBs), with a focus on environmental objectives and circular strategies.

We examined recent literature on timber architecture (post-2020) and integrated these insights with practical applications discussed by scholars. By synthesizing and summarizing existing research, this review aimed to identify knowledge gaps and general barriers to adaptation in multi-storey timber buildings. It is important to note that this review aimed to highlight the state-of-the-art application of adaptable design strategies and barriers to adaptation in mass timber construction, rather than provide an exhaustive study.

Employing an inductive approach, we analysed the papers based on identified adaptation barriers. Given the research objectives, thematic analysis was chosen to identify and categorize circular economy (CE) design strategies during the initial stage of the review. This approach allowed us to synthesize key findings from the reviewed literature, identify gaps, and outline future research directions.

3 Timber-Specific Adaptation Barriers

3.1 Acoustics

Acoustic challenges in timber construction significantly impact adaptability. The low mass of timber necessitates multi-layered systems to meet sound insulation requirements, complicating future modifications. These systems typically include double-leaf party walls, acoustic decoupling, false ceilings, and additional mass through screeds or infills. Exposed timber elements spanning multiple units are often unfeasible due to acoustic decoupling needs, and solid timber partition walls must be doubled for sound insulation [14].

Changes in apartment layout require adjustments to floor decoupling cuts, involving substantial structural alterations. Walls separating corridors from non-living spaces like hallways are built thinner than adjacent to living rooms due to different acoustic specifications [15]; leaving little room for change of use. While additional layers of gypsum boards, suspended ceiling systems, fillers, intermediate insulation and decoupling elastomers enhance acoustic performance, they compromise structural clarity and future adaptability. The key challenge lies in balancing immediate cost-effectiveness, acoustic and structural performance with long-term flexibility in timber structures.

3.2 Prefabrication, Connections and Standardisation

Prefabrication in modern timber construction offers efficient assembly but can create challenges for adaptability. The integration of structure, facade, and services in compact modules may hinder selective replacement or upgrading, particularly when services are concealed behind structural linings. Custom-designed solid timber products like cross-laminated timber (CLT) may have limited reuse potential in different contexts. Transport size restrictions can impact room dimensions and ceiling heights, with panelised buildings typically having net ceiling heights between 2.4 and 3.5 m [16], whereas in other building systems this is less a constraint.

Connections must withstand multiple assembly-disassembly cycles while resisting friction, creep, and corrosion [17]. Deconstruction effort and cost depend on element size and weight, connection type and number, damage potential, removal direction, health and safety regulations and location within the building. While hooking brackets allow vertical disassembly, current market limitations in CLT wall-to-floor connections restrict horizontal disassembly, creating friction between modular design intentions and technical feasibility [18]. Disassembly may require heavy equipment like cranes and temporary scaffolding, similar to the construction phase, limiting feasibility.

Prefabrication trends favour rectilinear volumes and regular flat extrusions for industrial efficiency. Standardized modular grids, often based on 625 mm multiples due to the size of wood-based boards, can impose constraints on interior layouts and facade design. Deviations from this geometry increase costs, potentially limiting design freedom and adaptability to complex urban contexts or future volume requirements [19]. While the rectangular grid plan layout offers simplicity, legibility and spatial planning, it may overlook architectural expression and spatial optimisation through its structure.

3.3 Structural Depth and Span

Design for Adaptability (DfA) principles, which favour open-plan, post-and-beam structures with large spans and tall floor-to-floor heights, face challenges in timber construction. Serviceability constraints limit floor and beam spans and larger spans and ceiling heights increase material costs and reduce resource efficiency [12]. The adaptability of timber structures is also shaped by their configuration. Vertically offset floor plans are generally unfavourable, while creating large column-free spaces demands significant effort. Conventional timber elements restrict flexibility because of their unidirectional load-bearing nature. While CLT slabs can span up to 6 m, commercial spans of 9–12 m often require composite timber-concrete or hollow box slabs such as Kerto Ripa (up to 8 m) or Lignatur (up to 10 m). Adapting a building with shorter timber spans may necessitate significant structural interventions [20]. Furthermore, timber systems with spans comparable to concrete often result in greater structural depth, with beams and girders impacting partition wall placement and limiting interior flexibility.

Volumetric aspects further limit adaptability. To achieve similar spaciousness as steel structures, timber buildings often require larger volumes, increasing enclosure areas and energy loss. Height restrictions in timber buildings exacerbate this issue, as additional structural depth reduces ceiling heights—one of the key barriers to adaptability [12, 21]. Addressing these limitations in span, volumetry, and structural rigidity is critical to achieving spatial overcapacity for adaptable multi-storey timber buildings.

3.4 Lateral stability

Timber buildings, due to the lower flexural stiffness of wood, depend on specific lateral force-resisting systems with shear walls, cores, and bracing to manage lateral loads such as winds or earthquakes. These systems are critical for structural integrity and include horizontally planar diaphragms or bracing and vertically shear walls, cores, bracing, or moment-resisting frames. Altering these systems can jeopardize stability, necessitating meticulous analysis and often extensive retrofitting.

While popular in mid-rise timber buildings, shear walls limit internal layout flexibility since they must align vertically across storeys. For instance, solid wood shear walls may restrict adding openings, making them unsuitable for flexible spaces like offices. Conversely, bracing can be architecturally integrated to minimize its impact on open spaces. Moment-resisting connections are hard to achieve, making large rigid frames without braced façades infeasible [14]. Bracing elements such as glulam or steel may conflict with façade permeability, refitability or later additions like balconies. In modular construction, bracing is often integrated into edge modules using steel-wood combinations, complicating future modifications [22].

Central cores are another common solution in multi-storey timber buildings (MTBs), offering structural stability while optimizing floor plans by enhancing circulation and natural light access. However, as core are semi-permanent, their materiality and location govern refitability and scalability.

In seismic regions, the ductility of connections allows for deformation without failure. However, permanent deformation of connections (e.g. unidirectional carpentry joints) hinders disassembly and reuse [17].

To ensure adaptability in timber construction, structural components for lateral stability must be carefully coordinated with architectural design to avoid conflicts with programmatic spaces.

3.5 Fire Safety

Timber's predictable charring rates allow for engineered fire resistance, yet building codes often impose stringent fire-resistance requirements on MTBs that complicate adaptation without extensive structural modifications. Effective fire compartmentation is a key constraint, limiting floor plan areas to avoid reliance on immovable interior firewalls [23]. Solutions like fire shutters at each ceiling level and separate shafts per fire compartment restrict spatial reconfiguration.

To achieve "highly fire-retardant" classifications, floor assemblies incorporating materials such as wet screed or gypsum fibre dry screed offer both safety and design flexibility. However, regulatory frameworks often restrict the use of exposed timber, particularly in escape routes. Encapsulation for fire protection also hinders demountability and impairs the simplicity, accessibility, and legibility of the structure, reducing its adaptability.

Finally, repairability is critical for timber structures damaged by fire or water. Yet, initial designs rarely consider the possibility of modifications to load-bearing elements, increasing the likelihood of full demolition after localized damage [13].

3.6 Services

The integration of building services, such as HVAC systems, fire protection, electrical conduits, and plumbing, poses significant adaptability challenges due to differing requirements for office and residential uses. Service layouts, whether linear or dispersed with multiple shafts and structural perforations, enhance flexibility during use but create friction between structure and services during future modifications [16].

Structural grid and beam orientation also influence service integration. While joisted floors without integrated channels facilitate modifications, they may require increased floor heights. Strategic placement of service openings mid-span minimizes structural impact but constrains refitability. Embedding services within floors can conflict with fire safety and acoustic requirements, limiting future changes unless modular designs or access panels are implemented.

Integrated timber elements further constrain adaptability. Pre-planned openings such as airtight cavity wall sockets are essential for maintaining airtightness and fire safety, with post-construction modifications potentially compromising these properties. Also, in milled recesses of CLT walls, repeated rerouting can compromise wall stability, fire rating, and soundproofing due to the difficulty of properly refilling these cavities.

3.7 Moisture, Airtightness and Thermal Insulation

Moisture, airtightness, and thermal insulation are critical considerations in timber construction due to the hygroscopic nature of wood, which demands robust moisture control strategies to preserve the structural integrity and durability of timber elements. While thermal bridging is less significant in timber structures, addressing moisture concerns requires careful implementation of (moisture-adaptive) vapor barriers, particularly at junctions between structural components. However, integrating the structure behind the vapor barrier or airtightness layer in façades reduces refitability [14].

Timber structures are particularly vulnerable to water damage, necessitating meticulous sealing of leak-prone areas. These areas may change during conversions, further complicating adaptation. Unlike mineral buildings where such issues are rarely structurally critical, maintaining moisture control adds complexity to façade modifications or wet room relocations, thereby impacting adaptability in MTBs.

4 Limitations and Opportunities for Timber-Inclusive Adaptability Frameworks

Several material-specific challenges remain largely unaddressed in the timber literature on adaptability. Current strategies for adaptability are often too broad and fail to consider the technical requirements and their timber-specific solutions. For instance, acoustic measures are only mentioned by Birk (2023), while Design for Manufacturing and Assembly is discussed by Ottenhaus et al. (2023), Öberg, Jockwer, and Goto (2024), and Hasani and Riggio (2025). Fire safety measures are covered by Laboy (2022), Birk (2023), Öberg, Jockwer, and Goto (2024), and Hasani and Riggio (2025). The focus of current adaptability research is primarily on structural depth and span, which is recognized as a barrier in timber literature [14].

Moreover, lateral force resistance systems are not considered a barrier to adaptation in the adaptable timber cases studied by Hasani and Riggio (2025), as these elements have been strategically placed. In the project descriptions of these predominantly low-rise buildings, adaptability is highlighted, suggesting that the placement of elements such as shear walls was a key consideration during the design process. This contrasts with regular timber buildings, which may overlook this aspect. Therefore, the importance of lateral stability measures for regular multi-storey timber buildings (MTBs) remains significant.

Additionally, unlike brick architecture, where uni-layer load-bearing walls can serve multiple functions, planar timber elements rarely exhibit such overcapacity. These gaps highlight the need to reassess the existing adaptability strategies for timber construction. Given the numerous adaptability frameworks available, it is essential to verify the incorporation of timber-specific adaptation barriers and identify the most valid framework to serve as the basis for a timber-inclusive adaptability framework.

5 Conclusion and Future Research

This study reveals a significant gap between existing adaptability criteria and the unique characteristics of timber construction in multi-storey timber buildings (MTBs). Current design strategies, while valuable, often lack aspects specific to timber construction, such as acoustics, fire safety and lateral stability. To address this, future research should include an assessment of the current adaptability frameworks with a case-study analysis of timber building systems.

The study is limited by the accessibility of literature and real world-applications. However, it sets the stage for developing specific design strategies for adaptable MTBs and potentially a material-inclusive adaptability framework. By addressing these priorities, future research can create robust tools that enhance MTB adaptability and contribute to broader sustainability goals, unlocking timber's full circular potential.

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