The impact of demountable connections on effective use of materials in timber structures

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Abstract

The construction industry is responsible for much global carbon emissions and resource depletion. As it moves towards a circular economy, the use of demountable timber connections could reduce material waste and improve efficiency. This paper looks at how these connections affect the use of materials in timber structures. It compares traditional fixed connections with various market-available and demountable ones, and how this affects material consumption, performance and reusability.

A combination of theoretical calculations, finite element modelling and case study analysis was used to assess the viability of these connections. Results show that demountable connections can significantly reduce material use without impacting structural integrity. They also facilitate ease of disassembly and extend the lifecycle of components. However, challenges remain, including standardisation, long-term durability, and the need for further research on the behaviour of connections over multiple use cycles.

Keywords: Demountable connections, timber structures, material use, mid-rise buildings, circularity

1 Introduction

The building and construction industry is one of the most significant contributors to greenhouse gas emissions worldwide. Despite the need to reduce these emissions and reach the targets set by the Paris Agreement by 2050, the industry currently accounts for around 40% of global energy-related CO2 emissions. It is critical to reduce or even eliminate this environmental impact[1]. Solemnly focussing on the sustainability of building materials itself, is not sufficient to meet the targets of the Paris Agreement. An additional factor one must look at in achieving these goals is changing the way we design structures. The economy is transitioning from linear to circular, allowing for the reuse of elements without causing harm or destruction. A critical part of preventing structural damage is designing the structures and connections between those elements in such a way that they can easily be dismantled and reassembled. This paper aims to be a guide to help future designers in adopting demountable and circular building designs by highlighting the benefits and marking the raising challenges of sustainable construction.

The aim of this research is to determine what kind of demountable timber connections already exist and what the influence is on the effective use of materials in timber structures. This, in order to spur interest in building demountable structures and highlight some vulnerabilities that require further investigation.

2 Literature review

2.1 Environmental Impact of the Construction Industry

The construction sector is a major contributor to global carbon emissions and resource depletion, accounting for nearly 40% of global CO_2 emissions and generating around 750 million metric tonnes of construction and demolition (C&D) waste annually [2,3]. Current material recovery rates are only around 50%, with much of the recovered material being downcycled rather than reused in high-value applications [1].

The use of mass timber in construction has been identified as a key strategy to reduce embodied carbon emissions, as timber structures store carbon throughout their lifespan [4,5]. Research indicates that mass timber buildings can act as long-term carbon sinks, reducing environmental impacts when compare to traditional concrete and steel structures [6].

However, to maximize sustainability, the industry must adopt circular economy principles, which emphasize reusability, disassembly, and lifecycle optimization [7].

2.2 Circular Economy and Demountable Timber Structures

A circular economy (CE) approach in construction focuses on extending the lifespan of materials and components while minimizing waste generation [7]. Unlike the traditional linear economy model (extract-use-dispose), a circular approach involves designing buildings for adaptability, disassembly, and reuse [8].

The ISO 20887:2020 standard provides a framework for evaluating the disassembly potential of structures, ensuring that building components can be removed and reused without degradation [9].

Key strategies for circular timber construction include:

(1) Adaptability

Ensuring that buildings can be modified or repurposed with minimal structural alterations [10].

(2) Disassembly

Utilizing connections that allow easy removal and reinstallation without damaging materials [6].

(3) Lifecycle Optimization

Designing for multiple use cycles to maintain material value and structural integrity over time [11].

2.3 Strength and Durability of Recycled Timber

Timber elements degrade over time due to load history, moisture exposure, and aging. The strength classification of reused timber is a critical factor in ensuring structural safety, but current grading standards often underestimate timber strength, leading to excessive material use [12].

Studies comparing European timber grading standards show inconsistencies:

UNI 11035 (2010) and UNI 11119 (2004) underestimate timber strength by 48–54% [13].

Nordic standard INSTA 142 (2010) performs slightly better, though it also leads to overestimated material requirements [13].

To improve the assessment of recycled timber quality, researchers advocate for non-destructive testing (NDT) methods, such as:

1. **Stress wave transmission testing [14].**
2. **Dynamic modulus of elasticity (MOE) measurements [15]**
3. **Pilodyn penetration testing for density evaluation [16]**

These methods provide a more accurate assessment of material properties while preserving the integrity of reused timber elements.

2.4 Benefits and Challenges of Demountable Timber Connections

Demountable connections offer three advantages:

(1) Reduced material use

By allowing reuse, they minimize raw material consumption [6].

(2) Improved reusability

Components can be removed and reinstalled without damage [7].

(3) Lower environmental impact

Reduced waste generation and extended lifecycle of timber components [6].

However, significant challenges remain:

(1) Lack of standardization

Current Eurocodes do not provide clear guidelines for demountable timber connections [9].

(2) Long-term durability concerns

Timber connections may weaken over multiple use cycles, affecting their load-bearing capacity [6].

(3) Storage and logistics issues

Reusing timber elements requires better tracking and management systems to ensure efficient reintegration into new structures [5].

3 Research method and reference building

3.1 Research method

To start this research, the first task was searching for a timber building with traditional connections.

Next the loads and cross sections of those connections were determined and calculated in two and three dimensions.

Afterwards, the quest for demountable connections commenced. These solutions were implemented in the reference building and the demountable behaviour in the ultimate and serviceability limit state were ensured.

Finally, the cross sections of the elements were determined and added up to find the total amount of timber material used in each implementation to see what the impact of demountable connections on effective use of material in timber structures.

3.2 Reference building

A three-story office building in Germany is used as the reference building. The plans and all the relevant information were found online [17].

This is an office building with a total surface area of 1335 m². There are four main columns that transfer the loads from each floor to the columns. The columns are placed in a grid of 5,1x5,1 m². There is a corridor of 2,4m. Secondary beams are placed every 0,85 metres. This is visualised Figure 1 and Figure 2. There were some modifications applied to the original existing building to ensure that the building structure was as standard as possible and that some trivial details would not influence the end result of this research. The secondary beams transfer the load from the floor to the main beams. The four transversal beams are the main beams, and they transfer the load to the columns.

The four connections that will be examined in this thesis can be retrieved in Figure 2.

The used, non-demountable connections are visualised in Figure 3 ,Figure 4 and Figure 5.

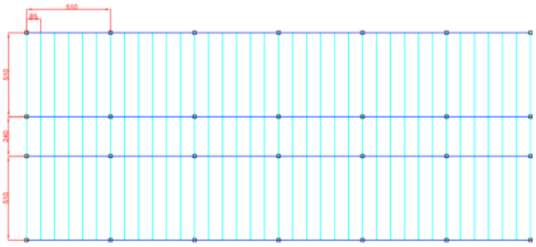

Figure 1: Floor plan reference building

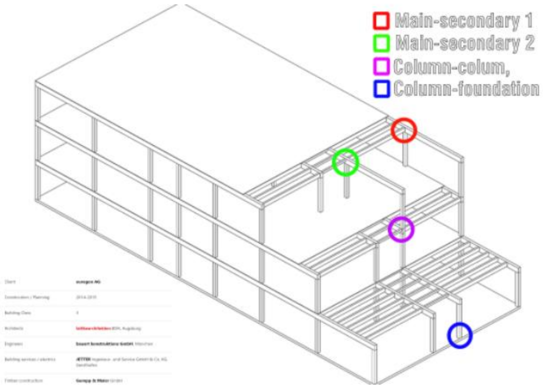

Figure 2: Different connections in 3D view [17]

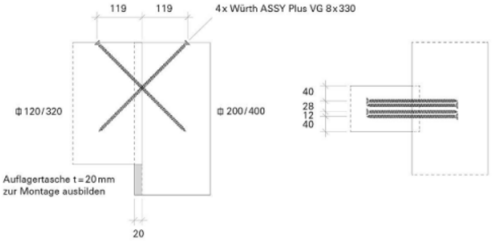

Figure 3: Connection main and secondary beam 1 roof [17]

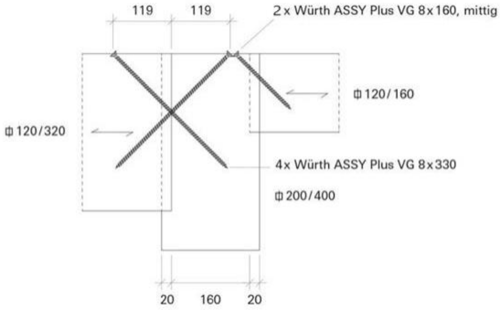

Figure 4: Connection main beam with secondary beams B roof [17]

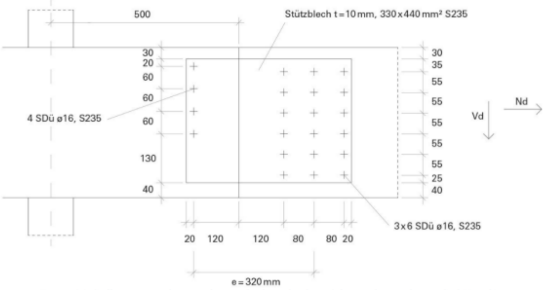

Figure 5: Stiff connection between beams [17]

The loads on and of the elements were determined based the cross-sections and Eurocodes.

The design loads applied on the building to calculate the traditional connections can be retrieved in Table 1.

Table 1: Design surface loads

Element	**Surface load [kN/m²]**
1st and 2nd Storey floor	8,87
Roof	1,85
Walls	0,73

3.3 Theoretical calculation

The load bearing capacity of existing, traditional screwed connections were calculated and checked based on calculation methods described in Eurocode 5.

Table 2 summarizes the load bearing capacities of the connections.

Table 2: Internal forces in non-demountable configuration

Connection	***Load bearing capacity [kN]***
Main beam to secondary beam 1	25,28
Main beam to secondary beam 2 left side	25,28
Main beam to secondary beam 2 right side	13,11
Beam to beam connection	17,06

Also, the stress bearing capacity of the columns were checked and met the requirements. [14]

It is clear that during the static design a high utility ratio can be obtained both for the elements and for the connections. This is primarily attributable to the fact that the design is also performed in the plastic behaviour of steel and the broad variety of types of screws that can be case specific. Further in this work ways of connecting which are demountable will be considered. Also, it will be examined how much material they use in order to bear the same forces.

4 Implementation of demountability for timber connections

4.1 Approach to performed research

To maximise independence and modularity, it is assumed that every part of the connection can be reused and replaced without harming the other parts of the connection. The elastic area of the stress-strain diagram serves as the basis for the connection's design.[6] If components of the connection deformed plastically, it would be impossible to remove them without modifying the beam or the connection. This implies that we consider the maximum stress of the connection to be the yield stress, as it represents the transition point between elastic and plastic behaviours, as demonstrated in Figure 6:Typical stress-strain curves for S235JR and S355J2G3 steels basing on [13]. To prevent distortions, divide the design strength by 60%, as the yield stress represents 60% of the ultimate stress. By designing the connection for only 60% of its maximum capacity, the influence of service life on timber is also taken into account. The strength of a timber element decreases by 20% due to biological degradation by moisture changes, moulding, grain slope changes, etc. [19]

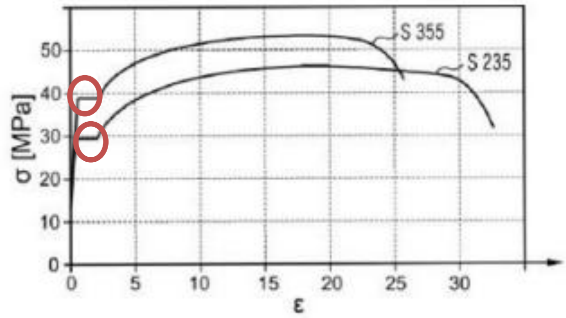

Figure 6: Typical *stress-strain curves for S235JR and S355J2G3 steels basing on [13]*

The demountable design prioritizes demountability and modularity for ease of maintenance and adaptability. Visible and easily accessible connections are preferred for straightforward disassembly. In the central corridor, smaller beams create a technical duct, simplifying the replacement of plumbing and electrical systems, which have a shorter lifespan than structural elements.

A key change from the original design is the use of continuous columns from the foundation to the roof, with individually connected main beams. This enhances modularity by allowing easy repair, removal, or reuse of beams, while continuous columns enable floor height adjustments without removal. This approach improves the building's simplicity, longevity, and adaptability.

4.2 Solutions

This paragraph examines the main-to-secondary beam connections, the main beam-to-column connections, and finally the column-to-floor connections, instead of column per floor.

An important note to mention is that there are several options for each solution. Due to the interpolation of different cross-sections, the DLUBAL finite element software produced varying internal forces, as this method accounts for the influence of different cross-sections. Due to the interpolation of different cross-sections, the DLUBAL finite element software produced varying internal forces, as this method accounts for the influence of different cross-sections. There was no need for an extensive iteration process because there are already several rather safe assumptions regarding the connection's behaviour.

Furthermore, the difference between the cross sections was relatively small, so there was no significant difference in the connection forces.

4.2.1 Rothoblaas

An adequate solution for implementing demountable connections are solutions from Rothoblaas.

The provided calculation tool, “Myproject”, was used to find a connection that meets the requirements and to calculate the amount of material.

The maximum internal force equalled 76.25 kN.

The corresponding minimum beam dimensions can be found in Table 3. The total timber consumption was 154m³ in order to build the structure. The specific connection and its technical data sheet can be retrieved in [18].

Table 3: Material use implementing Rothoblaas' solution

Element	b [m]	h [m]	l [m]	Amount	V [m³]
Main beam	0,28	0,64	30,6	12	65,8
2nd beam 1	0,18	0,26	5,1	222	53,0
2nd beam 2	0,16	0,16	2,4	111	6,82
Columns	0,32	0,32	9,9	28	28,4
Total					154

4.2.2 Knapp verbinder

To find a solution provided by Knapp Verbinder, the catalogue was assessed. The maximum internal force present for this solution was 80,87 kN.

Consequently, also the provided cross-sections were checked in DLUBAL to also meet the serviceability limit state requirements, and the results are shown in Table 4 . The specific connection and its technical datasheet can be retrieved in [18].

Table 4: Material use implementing Knapp verbinder's solution

Element	b [m]	h [m]	l [m]	Amount	V [m³]
Main beam	0,14	0,64	30,6	12	32,9
2nd beam 1	0,12	0,32	5,10	222	43,5
2nd beam 2	0,10	0,16	2,40	111	4,26
Columns	0,32	0,32	9,90	28	28,4
Total					109

4.2.3 Simpson Strong Tie

The maximum internal force, retrieved from DLUBAL, in this set-up is 73,95kN.

Since there was not yet provided a solution from Simpson Strong Tie for the connection of the main beam, the least material consuming solution from another company, Knapp Verbinder, was used.

The material use is listed in Table 5.

Table 5: Material use implementing Simpson Strong Tie's solution

Element	b [m]	h [m]	l [m]	Amount	V [m³]
Main beam	0,14	0,64	30,6	12	32,9
2nd beam 1	0,12	0,32	5,10	222	43,5
2nd beam 2	0,14	0,20	2,40	111	7,46
Columns	0,32	0,32	9,90	28	28,4
Total					112

4.2.4 Sherpa connectors

The maximum internal force in this case was 74,50kN. The connector was drawn from the catalogue by diving the by 0,6 to stay in the elastic field and recalculated to the characteristic force to find a suitable solution. The amount of timber needed to establish the building can be found in Table 6. The specific connector used for each connection can be found in [18].

Table 6: Material use implementing Sherpa connector's solution

Element	b [m]	h [m]	l [m]	Amount	V [m³]
Main beam	0,28	0,64	30,6	12	65,8
2nd beam 1	0,20	0,32	5,10	222	72,5
2nd beam 2	0,12	0,16	2,40	111	5,11
Columns	0,32	0,32	9,90	28	28,4
Total					171

4.3 Column to foundation connection

Although some demountable column-to-foundation connections already exist, their design for residential rather than industrial applications limit their ability to handle relatively small reaction forces. As a result, this foundation requires a case-dependent, engineered solution. The system that will be applied is based on a steel pillar column foot A steel pillar was chosen foot since the material properties of steel are more beneficial than those of timber for this kind of application. It can bear a higher-pressure force, and it is not prone to water degradation. It is crucial to bear in mind that this is the ground level, and water contact is likely due to floods, rainfall, cleaning, and other factors. In all cases, the columns have a cross section of 320 x 320 mm². This pillar is made up of two steel plates connected to a steel tube that is at least 10 cm long. Since all the columns in this solution have the same cross section of 320x320 mm², it led to the decision to use a metal plate of 320x320mm².

The exact calculation and determination can be found in [18].

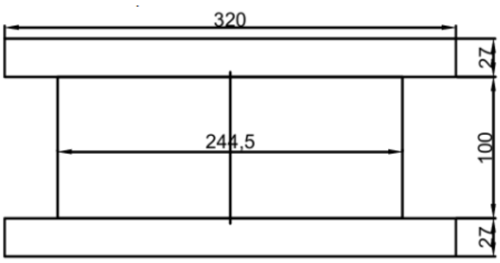

Figure 7: Column footing

5 Conclusion

5.1 Conclusion based on material use

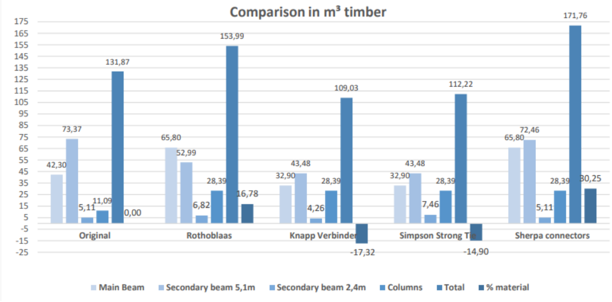

Figure 8: Comparison in material use for each element

This study investigated the impact of demountable connections on material efficiency in timber office buildings. The comparative analysis of different connection solutions revealed significant variations in timber consumption, as illustrated in *Figure 8* and

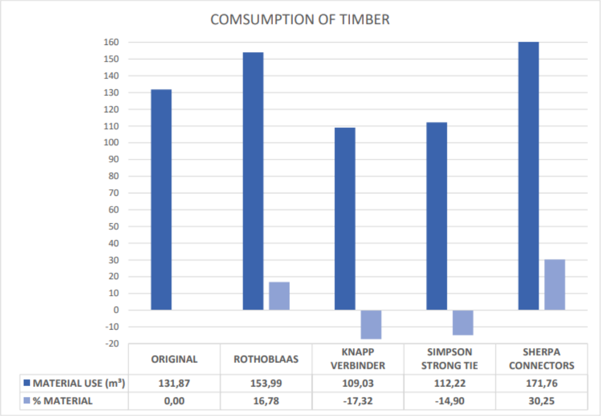

Figure 9.

The KNAPP Verbinder system demonstrated the highest material efficiency, utilizing the least

timber while maintaining an optimal utility ratio.

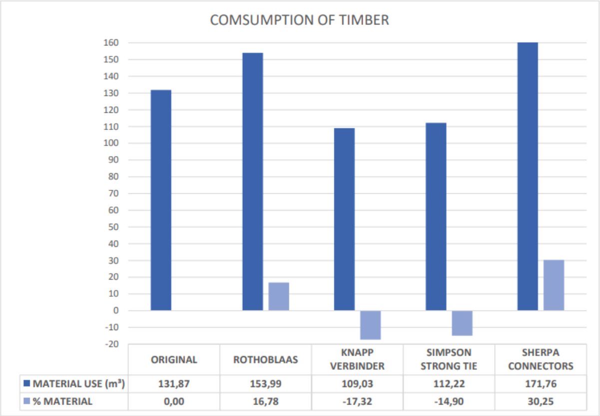

Figure 9: Total material use and percentage compared to original situation

The Simpson Strong-Tie solution also proved to be a viable alternative with relatively low material consumption.

The Rothoblaas system, despite increasing material use by at least 16,8%, offers the advantage of demountability, which may justify the additional cost in the context of long-term adaptability and sustainability. Sherpa Connectors, with a 30.25% increase in material use compared to traditional methods, adopts a highly conservative design, incorporating stress considerations in the secondary beam. This results in significantly higher material demand but ensures structural robustness.

Utility ratios further clarify the efficiency of each system. The KNAPP Verbinder solution maximizes material efficiency, albeit with minimal tolerance for errors. Rothoblaas, while consuming more material than KNAPP as well as Simpson Strong-Tie, maintain a high utility ratio. Sherpa Connectors, designed with a conservative 88% utility ratio, lead to the highest material use but prioritizes structural safety.

Optimizing missing design information and refining connection methodologies are crucial for enhancing material efficiency and long-term sustainability. Constructing columns as single, continuous elements rather than segmented components can contribute to greater design flexibility but necessitates larger cross-sections, increasing material use. However, in the long term, this approach offers greater adaptability in floor height and room spacing, reinforcing its sustainability benefits.

While demountable timber connections remain an emerging field requiring further research, this study confirms that, when designed correctly, such systems can reduce material consumption and extend the service life of timber office buildings. This underscores the potential of demountable construction to offer a sustainable alternative to conventional building methods.

5.2 Potential for society

Beyond environmental and sustainability considerations, demountable timber connections also present significant social benefits. As discussed in section 1, demountable buildings can adapt and grow alongside their occupants, enhancing long-term usability and reducing housing waste. Additionally, such construction methods offer potential applications in emergency shelters. Since timber is a relatively lightweight material, it can be transported and assembled more easily than concrete. Moreover, its dry construction process, relying on mechanical connections rather than wet adhesives, significantly reduces construction time. These properties make timber highly suitable for temporary and relocatable structures. Given that all timber elements and connections are designed to remain within the elastic deformation range, minimal damage occurs during disassembly, allowing components to be reused efficiently with minimal degradation.

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