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Inventory of Timber in Finnish Residential Houses

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ABSTRACT

To better understand the reuse and recycling potential of timber available within buildings, this paper creates an inventory of timber used in the construction of building typologies in Finland by analysing the technical documents of twenty typical houses and suggesting timber components that might be the best for reuse and recycling.
The analysis showed that Finnish buildings contain timbers that could be reused and recycled. This highlights an opportunity and a need for the development of guidance on the principles and strategies for design for deconstruction and reuse. It was also determined that due to the design of these buildings, it is currently uneconomic to extract the timber components intact, even if they could be reused or repurposed. By making only minor changes to existing design, construction, and demolition practices, significant possibilities for reusing and recycling may be generated, adding value to timber, and reducing the demand for virgin wood.

KEYWORDS

Reclaimed timber, Wood, Timber, Residential buildings, Reuse, Recycling, Waste

INTRODUCTION

In Europe, the importance of resource efficiency has recently been highlighted and can be achieved through the reduction, reuse and recycling of reclaimed materials and energy [1,2]. The efficient use of reclaimed materials embodied in the building sector is essential, as the sector consumes around half of all materials produced annually [3]. In addition, the construction and demolition industries are responsible for 46% of annual waste in Europe [4]. Amongst all waste materials from the construction and demolition industries, wood waste has a low degree of reuse and recycling into products [5]. In Europe, most wood waste arising from construction and demolition projects is burnt for the generation of energy [6]. However, wood waste could have higher utility and value should it be reused and upcycled before eventually being used for energy generation [7, 8, 9]. The use of reclaimed timber contributes to better material recovery rates, extending their life cycle and lowering greenhouse gas emissions [10]. Significant efforts are still needed, however, to achieve this.

In the absence of biological degradation, the natural ageing of wood does not necessarily result in significant loss in properties [11]. Thus, the quality of wood that has not been damaged or contaminated in the use and end of life stages of a building lifecycle, often makes reuse and recycling preferable to burning for energy [12,13]. Currently, there is no knowledge about the size, amount, and recoverability of timber and timber products after the first use and the paucity of such information does not allow reuse and recycling to be implemented. To better understand the potential of timber within buildings, this paper creates an inventory of timber used in the construction of typical building typologies in Finland by analysing the technical documents of twenty typical houses and suggesting timber components that might be the best for reuse and recycling. This can then be combined with other parameters, such as material stock analysis, survival analysis and quality of reclaimed timber, to forecast the future availability of recoverable timber [14].

The buildings analysed in this study were Finnish residential houses commonly built in 1940s and 1950s with timber structures. The estimates indicated that approximately 17.5 million tons of timber are encapsulated in structural elements of Finnish residential houses, of which around 51% is theoretically reusable and recyclable [15]. Houses built between 1940-1959 contained the highest amount of timber (around 4 million tons of timber) by far, compared to other periods.

Most of the selected houses used the balloon framing technique with gable roof framing and a stone-structured cellar [16]. They were 1-2 storeys in height and used external board cladding for the façade. The balloon frame technique consists of full-height wall framing elements which usually use sawn timbers, assembled with nails [17]. The studs are attached to all structures of the house, from roof elements to intermediate floor joists, and the bottom plate. The spaces between studs are usually 500-700 mm wide which was later standardized to 600 mm [18]. The spaces between studs are filled with an insulating material, such as sawdust. The roof joists, intermediate floor joists, and roof structures are also nailed to the wall studs with matching spacing. The battens were also placed with around the same spacing. The spaces between battens are filled with an insulating material. In the following decades, long continuous studs were dispensed with, single storey long studs which were constructed as separate platform for over two storey buildings (so-called platform framing) [16].

MATERIALS AND METHODS

System boundary

Only timber and timber products used for structural purposes during the construction stage were investigated in the current study, as they potentially have high value for reuse and recycling. Hence, the following timber and timber products were not analysed in this study:

- Renovation, refurbishment, extension, and modernization measures.
- Non-structural applications, furniture and surface materials (doors, stairs, floorings, etc.).
- Formwork, packaging, and waste from timber processing on the construction site.
- The foundation as it is usually constructed with stone and concrete.
- Wind cover boards, and closet walls.

All structural components within roofs (e.g., rafters, struts, collar beams, battens), external and dividing walls (e.g., external cladding, studs, diagonal boards), and floors (e.g., joists, battens, beams) were considered in the calculation of the total volume of timber available in the buildings.

Materials

Technical documents of all buildings were collected from the “Digital Archives” (digi.narc.fi) of “National Archives of Finland” (arkisto.fi) who is responsible for digitizing type houses, that were built in Finland between 1918-1964 [19]. Technical documents of every selected building contained drawings (e.g., floorplans, sections, elevations, joists and beam plans) and a bill of materials.

Information about the building type, construction period, construction method, number of storeys, number of dwellings, and the gross floor area were recorded for every building. Amongst all the aforementioned features, the building type, construction period, and gross floor area were used to produce a code for each building, as shown in Figure 1. First, the buildings were named according to building type, detached houses (DH). Then, the buildings were categorized by construction period and by gross floor area. For instance, DH-1950-93 represents a Finnish detached house that was constructed in the 1950s and has a gross floor area of 93 m^2.

Table 1. Standardized buildings analysed in Finland; f= floor, b=basement.

Code of buildings	Building type	Construction method	Number of storeys	Number of dwellings
DH-1950s-150	Detached farmhouse	Balloon framing	1.5f+b	1
DH-1950s-174	Detached farmhouse	Balloon framing	2f+b	1
DH-1950s-224	Detached farmhouse	Balloon framing	2f+b	1
DH-1950s-139	Detached farmhouse	Balloon framing	2f+b	1
DH-1950s-154	Detached farmhouse	Balloon framing	2f+b	1
DH-1950s-173	Detached farmhouse	Balloon framing	2f+b	1
DH-1950s-183	Detached farmhouse	Balloon framing	2f+b	1
DH-1950s-101	Detached house	Balloon framing	1.5f+b	1
DH-1950s-120	Detached house	Balloon framing	2f+b	1
DH-1950s-147	Detached house	Balloon framing	2f+b	1
DH-1950s-164	Detached house	Balloon framing	2f+b	1
DH-1950s-091	Detached house	Balloon framing	2f+b	1
DH-1950s-128	Detached house	Balloon framing	2f+b	1
DH-1950s-122	Detached house	Balloon framing	2f+b	1
DH-1950s-109	Detached house	Balloon framing	2f+b	1
DH-1950s-109	Detached house	Balloon framing	2f+b	1
DH-1950s-165	Detached house	Balloon framing	2f+b	1
DH-1950s-142	Detached house	Balloon framing	2f+b	1
DH-1950s-188	Detached house	Balloon framing	2f+b	2
DH-1950s-199	Detached house	Balloon framing	2f+b	2

Methods

To collect data in a unified format an inventory sheet was developed in the format is shown in Table 2. The dimension (cross-sectional size and length) of structural components was inserted in a tabular format upon analysing design drawings and the bills of material. For every timber component the following information was recorded: building element, location within the building, length (if available), cross-section, total length (if available), and quantity.

All the components within a building were categorized according to building element (e.g., roof, floors, walls), location within building, length, and cross-sectional size, as shown in Table 2. It was not possible to extract the length of some components from technical documents, so the total length was inserted. The total length is the total amount of timber delivered onsite for sawing and installation on-site.

Table 2. An illustration of an inventory sheet developed for data extraction from buildings. Below are the inventory data of the building code DH-1950s-224.

Building element	Location	Length (m)	Cross-section (mm×mm)	Total length (m)	Quantity of components per length	Volume per component (m^3)
Roof	Roof	5.8	40×125	-	30	0.87
		3.5	40×125	-	20	0.35
		4	40×125	-	34	0.68
		-	22×100	1997	1	4.39
		-	22×40	1105	1	0.97
	Attic	3	40×100	-	45	0.54
		2.5	40×100	-	40	0.40
		-	20×100	1700	1	3.40
		-	50×100	255	1	1.28
		-	40×125	85	1	0.42
		-	25×40	212	1	0.21
Floor	First floor	5.3	100×200	-	8	0.85
		4.3	75×200	-	22	1.42
		3	75×200	-	10	0.45
		2	75×200	-	4	0.12
		-	50×100	280	1	1.40
		-	25×40	297	1	0.30
	Intermediate floor	1	125×125	-	5	0.08
		3	125×125	-	2.5	0.12
		6	100×200	-	3	0.36
		5.5	100×200	-	2	0.22
		5.3	100×200	-	18	1.91
		4.3	75×200	-	10	0.64
		3	75×200	-	3	0.13
		2	75×200	-	4	0.12
		-	25×40	297	1	0.30
Wall	External walls	3.25	125×125	-	2	0.10
		6	40×125	-	8	0.24
		5.5	40×125	-	8	0.22
		4.8	40×125	-	4	0.09
		4.4	40×125	-	50	1.10
		3.25	40×125	-	6	0.10
		-	22×125	1530	1	4.21
		-	13×40	1530	1	0.79
	Dividing wall	-	20×100	3400	1	6.80
		3.2	100×100	-	5	0.16
		3.2	40×100	-	70	0.89
Total						35.76

The volume of each component was calculated with the following equations ($V_{component}$):

$$V_{component} = [A_{component} \times L_{component}] \times Count_{component} \quad (1)$$

Where $A_{component}$ is area of cross-section in m^2; $L_{component}$ is the length of component installed in the building; $Count_{component}$ is the number of components per length.

$$V_{component} = A_{component} \times (0.85 \times L_{all\ components}) \quad (2)$$

Where $L_{all\ components}$ is the total length of a cross-section in meters. $L_{all\ components}$ was inserted from the bill of materials, where it was not possible to do additional measurements according to design drawings. As the total length of components was taken from the “bill of quantity”, around 15% waste of the total length of components was assumed. This is a reasonable assumption as approximately 15% wastage from total length was stated in technical documents of the buildings as well.

To calculate the total volume of timber and timber products in a building. A summation of the volume of all components within a building was calculated, as shown in the last row of Table 2.

RESULTS AND DISCUSSION

According to Figure 1, the volume of timber is between 16.90 and 36.65 cubic meters in the selected buildings. Variations mainly result from the gross floor area of buildings and the number of storeys. The evidence does not support the conclusion that the number of dwellings affects the amount of timber encapsulated in buildings. The buildings analysed contain an average of 0.17 cubic meters of timber per square meter of gross floor area. Figure 1 also shows a strong positive linear relationship (R^2=0.91) between the volume of timber and gross floor area. A building's gross floor area is directly proportional to its volume of timber, although the relationship may vary depending on construction methods. Furthermore, building elements do not show a linear relationship to gross floor area.

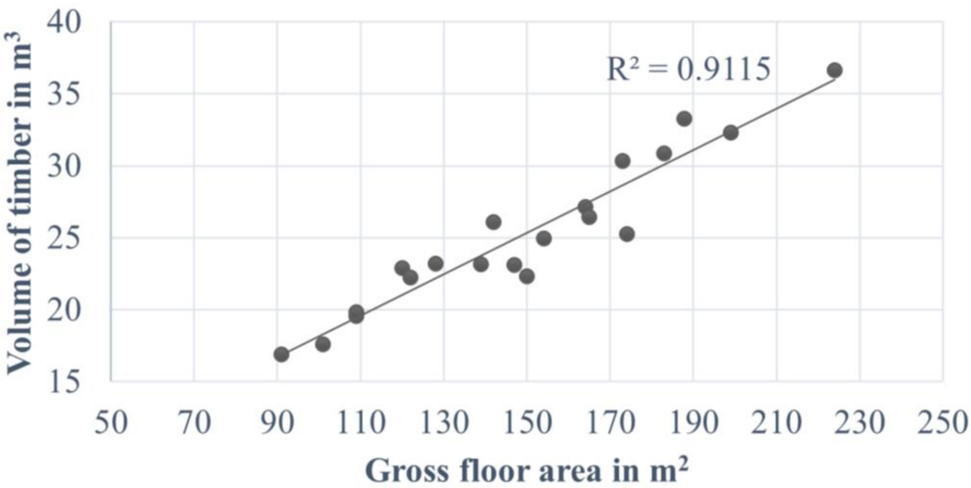

Figure 1. Correlation between volume of timber and gross floor area.

Amongst all building parts, dividing walls, external walls and roofs usually contain the most timber, on average 24%, 23% and 22% of total timber contains in a building (Figure 2). According to the third quartile of buildings, the total timber embodied in external walls and dividing walls is between 19-24% and 16-24%. The least amount of timber is encapsulated in intermediate floors with less variation between the analysed buildings. This may be due to the type of building analysed since they were 1-2 storeys buildings, and might be different for multi-storey buildings. Except for the intermediate floor and roof, all building elements of the analysed buildings vary in timber content by around 12-13%. The variation comes from not only the gross floor area and number of storeys, but the layout plan. According to Figure 2, the median lies closer to the first quartile on the intermediate floor, first floor, attic, and dividing walls, suggesting that the distribution is positively skewed. The opposite is true for external walls and roofs.

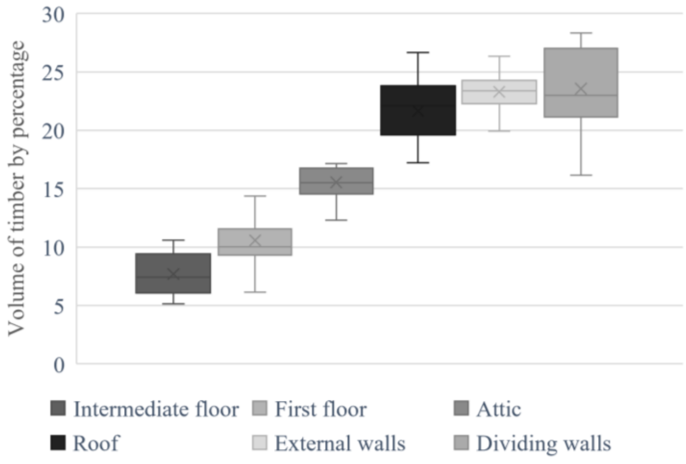

Figure 2. Distribution of timber contained in selected buildings by building element. Each box plot shows the average value through a cross symbol.

Figure 3 illustrates the eleven cross-sections commonly used in the structural parts of buildings. Almost all of these are longer than 2 m, except for the ones with unknown lengths. Besides the cross-section sizes illustrated in Figure 3, the following cross-section sizes are also occasionally used in some of the analysed buildings, but their proportion compared to the preceding cross-sections is minimal (below 9% of total): 75 mm × 150 mm, 75 mm × 200 mm, 60 mm × 200 mm, 50 mm × 200 mm, 100 mm × 100 mm, 100 mm × 200 mm, 50 mm × 50 mm, and 50 mm × 175 mm.

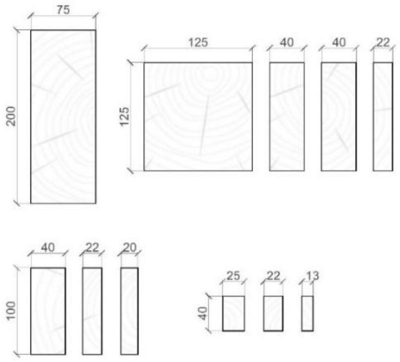

Figure 3. Cross-sectional sizes commonly used in the selected buildings.

Figure 4 illustrates that approximately 66%-73% of timber embodied in each building in terms of volume is made up of the following cross-sections: 22 mm × 100 mm (7/8" × 4"), 20 mm × 100 mm (3/4" × 4"), 22 mm × 125 mm (7/8" × 5"), 40 mm × 125 mm (1.5" × 5"). Timbers with 20 mm × 100 mm cross-section constitute by far the highest volume in all the buildings. In most buildings, the length of this cross-section is unknown due to the lack of relevant technical documents. Because the preceding cross-sections are used as structural sheeting for external and dividing walls, they are not suitable for reuse or recycling since as many as 40 nails per meter were used for their installation.

The most favourable option for repurposing was '40 × 125' (when disassembled), which was mainly used for studs, top and bottom plates, and rafters. Studies have shown that studs are typically made from 50 mm × 100 mm timbers, however the standardized houses analysed in the current study occasionally used a different dimension [24]. In general, the most prominent way of disassembling balloon framing walls would be disassembling the frames down to individual timbers. This is because studs are usually attached to several storeys. If the studs were deconstructed intact, the average timber length in balloon framed houses is generally long enough to be utilized in modern products or it could be broken down to smaller pieces for engineered wood products.

Removal of nails from roof structures is often difficult as some are installed in inaccessible places. Alternatively, roofs can be removed from the structure as a unit and disassembled afterwards, considering that it does not reduce the structural integrity of the whole structure. Upon disassembly, floor joists can also be reused as the length of floor joists are usually more than 2000 mm.

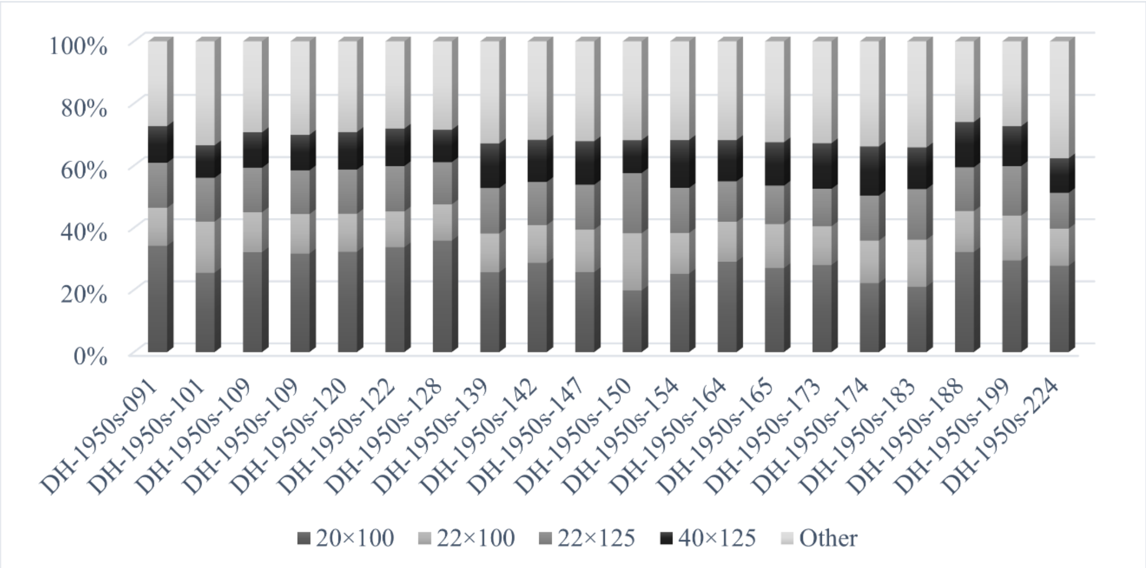

Figure 4. Percentage of timber contained in selected buildings by cross-section.

CONCLUSION

An analysis of twenty residential buildings commonly built in 1940s and 1950s in Finland revealed that timber available in existing buildings is potentially suitable for reuse or recycling. A clear opportunity and need exists for the development of accessible, practical guidance on the principles and strategies for design for deconstruction/disassembly and reuse that could be applied easily during the design process and on site. By understanding the consistency and nature of the existing housing stock as well as how we can deconstruct them, relatively minor adjustments can be made to design, construction, and demolition practices to generate significant opportunities for disassembly and reuse of timber components which would add value to timber products, buildings and reduce demand for virgin timber stocks from forestry.

Despite the wide use of timber construction in Finnish detached and attached houses [15] and the high value of timber used within them, there is a low degree of reuse and recycling. However, due to the design of these dwellings, it is currently uneconomic for demolition contractors to extract the timber components intact. Even when they can be reused or repurposed. For example, in the houses analysed, external walls start from the base floor to the second floor where they reach the pitched roof. These walls are usually attached to neighbouring structures, such as floors, roofs, and external cladding with nails which make it difficult and expensive to disassemble.

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NOMENCLATURE

Abbreviations and their definitions

Abbreviation	Definition
DH	Detached House
f	Floor
b	Basement

Symbols and their subscripts and definitions

<table>
<tr><th>Symbol</th><th>Subscript</th><th>Definition</th></tr>
<tr><td>$V_{component}$</td><td rowspan="4">Component: Timber with the same building element, location within building, length and cross-section.</td><td>Volume per Component</td></tr>
<tr><td>$A_{component}$</td><td>Area of Cross-section per Component</td></tr>
<tr><td>$L_{component}$</td><td>Length per Component</td></tr>
<tr><td>$Count_{component}$</td><td>Number of Components</td></tr>
<tr><td>$L_{all\ components}$</td><td>All component: Timber with the same building element, location within building, total length and cross-section.</td><td>Total length meter per component</td></tr>
</table>

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