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Innovative Design for the **Fut**ure – **U**se and **Re**use of **W**ood (**InFutUReWood**)

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Recovered timber in Europe: sources, classification, existing and potential reuse and recycling

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Innovative Design for the **Fut**ure – **U**se and **Re**use of **Wood** Building Components

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Foreword

This report is published under the InFutUReWood project - Innovative Design for the Future – Use and Reuse of Wood (Building) Components. Work Package 3.

The InfutUReWood project has seven work packages:

- WP 1 Coordination and management led by Karin Sandberg, RISE, Sweden
- WP 2 Design of timber structures for the future, led by Ylva Sandin, RISE, Sweden
- WP 3 Product design using recovered timber, led by Annette M. Harte, NUI Galway, Ireland
- WP 4 Inventory, deconstruction and quality of recovered wood, led by Mark Hughes, Aalto University, Finland
- WP 5 Properties of recovered wood, led by Daniel Ridley-Ellis, Edinburgh Napier University, UK
- WP 6 Environmental and economic assessment of design for recycling in building construction, led by Michael Risse, TUM, Germany
- WP 7 Dissemination and engagement, led by Carmen Cristescu, RISE, Sweden

ForestValue

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The research and academia project partners are RISE (Sweden), Edinburgh Napier University (UK), National University of Ireland Galway (Ireland), University College Dublin (Ireland), Universidad Politécnica de Madrid, (Spain), University of Ljubljana (Slovenia), Aalto University Helsinki (Finland), and Technical University Munich (Germany).

The industry partners are Kiruna Municipality Technical Service, Swedish Wood, Derome, IsoTimber, Offsite Solutions Scotland, Hegarty Demolition, SIP Energy, Connaught Timber, The Federation of the Finnish Woodworking Industries, Jelovica, The Swedish Federation of Wood and Furniture Industry, Balcas Timber, Stora Enso, Klimark + Nova domus Hábitat, and Brenner Planungsgesellschaft.

Summary

The Innovative Design for the Future Use and Reuse of Wooden building components (InFutUReWood) project aims to examine if recovered timber is suited for contemporary timber architecture. To address this aim, a study was undertaken as part of Work Package 3 to identify the current range of timber products obtained from demolition and their current and potential reuse. The study was conducted across all partner countries using a combination of site visits and industry surveys

The information compiled shows that the motivation for deconstruction in each country depends mainly on the building location and site value. The type of timber available for recovery was largely contingent on the age of the structures. Building deterioration and rising building standards were common causes for demolition; however, a more significant incentive for urban demolition was market depreciation. In these instances, site clearance makes way for redevelopment, facilitating alternative building use or general urban renewal.

An overview of international and national classification systems for timber waste from construction and demolition is presented. Differences were found between partner countries in terms of the potential to reuse recovered timber in loading bearing applications in buildings.

Most timber extracted from construction and demolition across the surveyed counties is reduced to woodchip, regardless the size or quality of the extracted material. The main uses of the wood chip are particle board manufacture or bioenergy generation. Exceptions to this are mass timber, such as glulam, and old, large section timber members with high cultural value, which are reused directly.

Potential alternative building products recovered timber are presented that will extend the lifespan of the material.

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1. Introduction

1.1. Background

The current EU Waste Directive [1] prompts Member States to regard waste as a resource [2]. In line with this general purpose the Innovative design for the Future Use and Reuse of Wooden building components (**InFutUReWood**) project aims to examine the current life cycle of timber in construction to establish the following:

- The effect of existing construction, demolition, and wood disposal practices on the quality of wood-salvage
- The current potential for reuse of building timber,
- Guidelines for timber product design (Design for Recycling (DfR)), that will improve the quality of wood-salvage in the future
- Practical systems for construction and deconstruction that will improve the potential yield of wood-salvage of a quality suitable for reuse.

It is intended to relay the findings of the project to the building industry to encourage and help sustain the circular economy in construction with respect to timber.

1.2. Aims and objectives

In all, the InFutUReWood project comprises seven Work Packages (WP-1 to WP 7). The objective of WP-3: "Product design using recovered timber", is to identify potential new timber products for construction that can be manufactured using wood-salvage.

This deliverable (D3.1) outlines the findings from the work undertaken in Task 3.1 "Specification of timber property requirements for products". The task was divided into the following objectives:

- To identify the typical range of timber products that are available from building demolition
- To establish the scope of the reuse and recycling of salvaged material currently
- To examine potential wood-salvage yield for reuse and recycling
- To explore the practical limitations of each application.

1.3. Scope of the report

This report outlines the details of data collected by the project partners from local industry to achieve the objectives of Task 3.1.

2. Data sources

The data for the study, unless otherwise specified, was collated from responses to a questionnaire that was developed by researchers at the National University of Ireland Galway (NUIG) and Aalto-Yliopisto (Aalto). The questionnaire comprised four parts:

- General information
- Demolition
- Waste management and waste sorting
- Recycling, reuse, and wood processing.

The following topics were examined:

- Demolition methods,
- Which building types are demolished currently
- The volume and type of timber-waste that is extracted
- The potential to recover good quality wood-salvage
- Current segregation of wood from other waste materials
- Wood waste management
- The existing timber-waste end-uses in the various regions.

The survey was circulated by email and/or conducted over the phone or in person. Supplementary observations at site visits are also included. A blank template of the questionnaire may be found in Appendix A.

2.1.1. General information:

A general background of the building types that are demolished and the common use of construction and demolition waste was provided by all the project partners.

2.1.2. Demolition:

Contributors to the study with respect to demolition methods included two contractors from Ireland, that included the leading and another provincial operator. Three demolition contractors that specialise in wood-salvage responded from the North of Spain, and two leading demolition contractors in Finland provided data to the survey. There was one respondent on demolition from Slovenia, one from the UK and one also from Sweden.

2.1.3. Waste management and waste sorting:

Responses on waste management and sorting included five leading waste management facilities in Ireland, five waste management facilities in Finland, including one of the leading companies in wood-waste sorting. There were three responses from the waste management industry in the UK, including one entirely specialising in wood and another with a specialised wood facility. The survey also included one waste facility in Germany, and one in Sweden.

2.1.4. Recycling, reuse, and wood processing:

One of the five waste management facilities surveyed in Finland produces recycled products from timber waste. There were five responses from the leading timber processors in Ireland, two timber waste processors from Spain and two of the UK general waste companies surveyed specialised in wood-salvage. A wood-waste processing plant and two wood recycling facilities contributed from Germany. A drop-off recycling amenity responded in Sweden.

The information provided on demolition practices was supplemented by a presentation given by InFutUReWood industry partner Paul Hogan of Hegarty Demolition Ltd., Dublin [3] to the project team.

3. Sources of recovered timber

The information compiled from the various surveys showed that the motivation for deconstruction in each country depended mainly on the building location and site value. The type of timber available for recovery was largely contingent on the age of the structures. Building deterioration and rising building standards were given as common causes for demolition; however, a more significant incentive for urban demolition was market depreciation. In these instances, site clearance makes way for redevelopment, facilitating alternative building use or general urban renewal.

3.1. Buildings for demolition

The following outlines the general information on buildings currently demolition in each country.

3.1.1. Finland

In terms of floor area, building demolition in Finland includes some dwellings, but mainly comprises multi-storey office and apartment buildings, warehouses, and other industrial structures, with a few schools, hospitals, laboratories, and some retail and church buildings also. Commercial and residential buildings predominately built in the 1950s to 1990s along with newer buildings, built after 2010, make up the stock of structures for deconstruction. The main incentive for urban demolition is for redevelopment. Other motivations include deterioration, outdated design, and poor building maintenance. The demolition contractors surveyed in Finland included large key players in the industry. Timber dwellings are also commonly demolished but more usually by smaller provincial building contractors.

3.1.2. Ireland

In Ireland, building typologies for demolition comprise residential, office, and retail construction [4]. The domestic buildings for demolition include urban-terraced and rural-detached dwellings that are more than 100 years old. One-off renovations of more modern suburban homes are also common, but more significantly is the demolition of urban or suburban multi-storey apartment, office, and retail developments that were constructed in the 1960s to 1990s, ranging up to 5-storeys high. Most commonly a complete or partial site clearance occurs to facilitate regeneration. Market value depreciation of existing structures is the main incentive. Low-rise construction is generally replaced with a higher density development expedited by updated urban planning rules. In other instances, high-rise social housing is replaced with a mixed and more diverse architectural landscape. Rising construction standards are also a significant motivation for redevelopment in Ireland.

3.1.3. Slovenia

The deconstructed buildings reported by one survey response in Slovenia comprised detached dwellings up to 100 years old, terraced housing from the 1980s, apartment buildings more than 40 years old, offices built in the last 20 years and retail units from the 1990s up to recent construction. The building heights vary up to four floors, but are mostly one-, and two-storey structures. As this Slovenian data comes from a single company, it may not be representative of the entire industry. Demolition is generally due to rising construction standards, poor building maintenance, and building depreciation. Small to medium size construction companies engage in small-scale demolition projects on national or regional level and demolish circa 50 - 60 dwellings per annum.

3.1.4. Spain

In Spain demolition comprises detached rural dwellings and some retail units that are between 50 to over 100 years old [4]. Industrial buildings, including mills and warehouses ageing from 30 to over 150 years are another primary timber source. An example is shown in Figure 1. Terraced housing is uncommon, except in coastal resorts from the 1960s; however, refurbishment of apartment blocks is usual in urban settings, where there is often a requirement to preserve the façade, as shown in Figures 2 and 3. Buildings over 100 years old, up to four floors high, will commonly yield wood-salvage. Office blocks and retail structures from the 1980s are also redeveloped but are normally constructed with steel and concrete. Deterioration from aging is the main motivation for the demolition of rural dwellings, with urban demolition facilitating regeneration mainly due to market value decline.

Figure 1: Derelict agricultural building, Northern Spain (Image by Daniel F. Llana)

Figure 2: Deconstruction in Northern Spain (Image by Daniel F. Llana)

Figure 3: Propping of urban building façade after main timber structure removed in Northern Spain (Image by Daniel F. Llana)

3.1.5. Sweden

Building demolition in Sweden comprises domestic housing, multi-storey apartment and office blocks, but predominately retail, commercial, and industrial development, with several schools of timber construction. The structures vary from single-storey buildings and mid-rise construction up to 30 m in height. The buildings generally date from the 1930s to 1950s and are demolished due to water and fire damage causing building fabric deterioration, outdated design and to accommodate redevelopment.

3.1.6. UK

The situation in the UK is similar. Buildings from the 1960s onwards are demolished mostly for economic or social reasons, to make room for more modern development. Some multi-storey concrete blocks from the 1960s are demolished due to material deterioration. In general, the number of timber buildings coming to the end of their life is negligible in the UK compared with steel and concrete construction. Modern domestic timber frame construction only became popular in the 1980s. The UK has a rich historic tradition of timber frame construction, however, these buildings are protected and maintained as a rule.

3.2. Brief overview of demolition practices

The survey responses revealed that the approach adopted to remove and dispose of building waste was largely contingent on the potential value of the material yield. The disposal of site waste is costly; therefore, competitive demolition management includes separation of building elements on site before transportation to recycling or to waste facilities, to avail of discounted fees for segregated material. Any reduction in the overall mass of waste improves the overall project cost outlay. Therefore, materials are reused, or sold whenever possible.

In all cases a deconstruction schedule is decided at pre-tender stage. While demolition tendering is price competitive, site access, the composition of the existing structures, preservation orders, material salvage, the public (including potential public opinion), the building condition, the potential effect on adjoining properties, and Health and Safety (H&S) are all considered when deciding the approach. An assessment of the existing mechanical and electrical services, ground works and sewers are generally included also. It is standard practice to inspect condemned or to be refurbished buildings for the presence of hazardous material (e.g. asbestos, creosote, lead, PCB (polychlorinated biphenyl), and microbes), which is removed pre-demolition for separate disposal. An asbestos survey is generally mandatory for any renovation or refurbishment project.

Building demolition can be described as (i) long-reach mechanical demolition as illustrated in Figure 4, or (ii) top-down, light-demolition, which is a combination of manual and mechanical disassembly, shown in Figures 5, 6, and 7. The deconstruction schedule may comprise a combination of methods and the approach significantly effects the condition of any potential material salvage.

3.2.1. Long-reach demolition:

Long-reach comprises mechanical demolition with a boom reach of up to 40 m. The whole structure is demolished in unison. The debris is then amassed at ground level, on site, for sorting post demolition. Some key characteristics of long-reach demolition are:

- It is the most cost and time efficient approach (20% cheaper than top-down deconstruction)
- At least one façade of the building is left exposed for the duration of the work. This prohibits any preservation from weathering of the existing building fabric
- Adequate area is required adjacent to the structure to facilitate the machinery, the storage and sorting of the debris
- Access to and around the building is critical, particularly to the structural supports of roofs and floors throughout disassembly
- Unsuitable site access or H&S concerns, including restricted access to main structural supports can make long-reach prohibitive
- The risk of falling debris during work, and damage to adjacent buildings, injury to members of the public, or to nearby thoroughfares are a concern
- Long-reach demolition is more destructive in terms of material salvage.

Figure 4: Long-reach demolition in Dublin, Ireland (Image from Hegarty Demolition Ltd. [5]***)***

3.2.2. Top-down-demolition:

Top-down (light) demolition involves a phased manual deconstruction, combining manual dismantling and the use of short-range machinery. The material is sorted as the work progresses. Key characteristics of top-down deconstruction are:

- This method is more labour intensive
- It is more costly
- This demolition approach is more suited to material salvage
- The existing floor structure must be reinforced to accommodate machinery, operatives, and debris
- Scaffolding is required
- The necessity of propping and scaffolding, along with a phased schedule of work makes this method less time efficient
- There is less chance of falling debris, harm to adjacent buildings, the public, or nearby thoroughfares
- Top-down demolition is usually less objectionable to the public.

Figure 5: Top-down demolition in Dublin, Ireland (Image by Paul Hogan, Hegarty Demolition Ltd.)

Figure 6: Top-down demolition in Dublin, Ireland (Image by Daniel F. Llana)

Figure 7: Top-down demolition in Dublin, Ireland (Image by Paul Hogan, Hegarty Demolition Ltd.)

The approach to deconstruction is similar in all the countries surveyed; however, some local practices were identified. It is common in Finland to remove the internal fabric of the building, including services, fittings, and furniture using light-demolition, then adopting a long-reach approach to deconstruct the external envelope. An assessment of the carbon footprint of the demolition works may be made. There is currently no resale market for timber salvage for reuse in construction in Finland apart from wooden roofing and siding shakes. In Spain the timber content, generally in older construction, comprises large structural beams that are valuable. Therefore, this wood-salvage is usually manually removed for resale. In Sweden windows and doors are removed initially and all materials are separated at the demolition site. An officer from local council tracks the route of the excavated material. Timber is separated from other materials in Ireland and the UK but cut or broken to sizes that optimise removal.

3.3. Classification of wood waste

The classification for wood separation and disposal and reuse restrictions vary across jurisdictions. This section gives an overview of international and national classification of wood waste from construction and demolition.

3.3.1. ISO classification:

A global standard from the International Organization for Standardization (**ISO**) **ISO/DIS 17300-1:2019** [6] on wood residue, post-consumer wood classification, and the efficient management of timber waste is at a final draft stage. It will cover the classification and identification of by-products and post-consumer (used) products, relating to forestry yield and from timber product manufacture. It will also include non-fuel applications for biomass.

3.3.2. EU classification:

The European classification system outlines a “List of Waste” (LoW) criteria [7]. Each waste type is defined by a six-digit code. The first two digits represent one of twenty chapters that define different waste origins. Wood waste is contained in Chapters **03** (Wood waste from panel, furniture, pulp, paper, and cardboard production), **17** (Construction and demolition timber waste), and **19** (Wood from waste management facilities). The same material can have a different code depending on its progression along the processing cycle. Construction and demolition timber waste is initially categorised **17**, but then re-categorised as **19** at the waste management facility. Some common codes applied to timber are:

- **170201:**
  Wood, non-hazardous building and demolition wood waste segregated from other materials on site
- **170904:**
  Mixed, non-hazardous building and demolition waste that is unseparated from other materials on site

- **191206:**
  Wood, hazardous. Timber adjoined to, coated, or treated with hazardous substances
- **191207:**
  Building and demolition wood waste (**170201** or **170904)** directly re-categorised at the waste management facility. Wood waste not included in **191206.**

3.3.3. Irish classification:

The Environmental Protection Agency (EPA) implements the Irish Waste Classification [8] system which is based on the European LoW criteria. Wood-waste generally is separated as hazardous or non-hazardous. It is anticipated that **ISO 17300** (3.3.1) will be adopted in Ireland on completion of its final draft.

3.3.4. Spanish classification:

The EU LoW criteria system is applied in Spain also, with wood-waste from construction and demolition regarded as hazardous or non-hazardous.

3.3.5. Finnish classification:

There are four wood-waste grades in Finland in accordance with (VTT [9]):

- **Grade A:**
  Chemically untreated construction wood, such as packaging wood-waste.

- **Grade B:**
  Surface coated and lacquered wood, or chemically treated and coated wood without halogenated organic compounds (e.g. PVC) and preservatives. No demolition wood is accepted. Construction wood-waste usually falls to this grade.

- **Grade C:**
  Wood waste containing halogenated organic compounds (e.g. PVC in coating) or containing heavy metals in excess of the threshold values for chlorine and heavy metals, given in Table 2 of the reference document [9]. Demolition wood-waste is usually classified as Grade C.

- **Grade D:**
  Hazardous wood, (e.g. railway sleepers and service poles).

Grades A and **B** are ordinarily not segregated, except if destined for particleboard production (**Grade A** only). Timber waste from demolition is generally sorted visually at the demolition site as:

- **Clean wood**: (**Grades B & C**)
  Containing no hazardous chemicals (**Grade C**)
- **Contaminated wood**:
  Containing hazardous chemicals (**Grade D, dark colour wood)**

At the recycling facilities, sorting is also visual, with additional back-up laboratory sample analysis bi-weekly or monthly. The frequency of laboratory testing highly depends on the sorting facility size as laboratory testing can be prohibitively costly for smaller businesses. However, additional laboratory testing could improve usable wood yield.

3.3.6. German classification:

Ordinance of requirements for the recovery of waste wood in Germany (Altholzverordnung) defines five timber-waste categories [2] [10] [11].

- **Grade AI**:
  Untreated or only mechanically treated wood
- **Grade AII**:
  Glued or painted wood (no halogen-organic compounds or preservatives)
- **Grade AIII:**
  Wood containing halogen-organic compounds; no preservatives
- **Grade AIV:**
  Contaminated Wood, including halogen-organic compounds, no polychlorinated biphenyls (PCB). All structural timber from demolition is included in this category.
- **Grade PCB:**
  Wood treated with PCB

The manufacturer and treatment details of waste are required by law over the life cycle of the products. Sorting is by visual inspection on-site and again at the waste management facility, with random sample chemical analyses. The Waste Wood Ordinance also distinguishes the wood suitable for reuse in material applications and that destined for incineration.

3.3.7. Swedish classification:

Sweden also sort timber waste as hazardous or non-hazardous with building industry guidelines classifying five types of wood-waste:

- **Impregnated**:
  Regarded as a hazardous material
- **Mixed**:
  Timber waste and off-cuts from building, renovation, (including DIY), and carpentry. This grade includes timber coated with non-hazardous paint and the presence of metal fixings
- **Clean wood**:
  Timber waste and off-cuts from carpentry that is free of coatings and metal fixings
- **Pallets**:
  Pallets are generally collected for reuse, repaired as necessary
- **Window frames**:
  Glass is separated from the timber frames at the recycling facility

3.3.8. UK classification:

The UK specification for processing wood waste is outlined in **BSI PAS 111:2012** [12], compiled by Publicly Available Specification (**PAS**), drafted in collaboration with the British Standards Institution (**BSI**), including consultation with the UK wood recycling industry. UK wood waste is categorized in four grades:

- **Grade A**:
  Solid wood, pallets, packing cases, and cable drums (untreated). Note that pallets are increasingly repaired and reused so this component of waste is diminishing.
- **Grade B**:
  Includes Grade A along with building and demolition timber and furniture made from solid wood, with limitations on treated and coated materials
- **Grade C**:
  Includes Grades A and B along with wood-based panel products, including chipboard, MDF, plywood, OSB and fibreboard. Painted, glued, coated, and treated timber are included
- **Grade D**:
  Hazardous material. This includes utility poles, sleepers, and fencing posts treated with carbonaceous chemicals such as CCA and Creosote.

The classification system is not mandatory and recycling facilities tend to use their own sorting systems, mostly for determining the price of wood waste. Chemical testing for hazardous contamination is not performed either by demolition or recycling companies. They solely rely on their contractors/ waste providers to inform them about hazardous contamination. Pallets are increasingly repaired and reused, therefore, this is a diminishing **Grade A** wood source in the UK.

3.4. Timber extracted from construction and demolition

The responses from all regions suggested that the demolition approach to timber construction is significantly dependent on the market demand for the wood-salvage. Large wood-only products that are generally more common in older buildings have an established route to market and are therefore removed carefully. Smaller wooden elements, and those integrated with other materials, that are generally from newer construction, are usually extracted with the other elements of the building mechanically.

3.4.1. Finland

In Finland, construction and demolition waste comprised 14% (15 million tonnes) of total waste in 2015 [13]. One of two prominent demolition contractors surveyed in Finland reported that timber-waste accounted for 14% by mass of the total waste from construction, renovation, and demolition (22% was classified as concrete or brick). Two recycling facilities reported processing 28,000 t of non-hazardous timber-waste in 2018. The product types included sawn timber, doors and windows, door and window frames, furniture, floorboards, parquet flooring, particleboard, fiberboard and laminates. All wood-waste segregated on demolition site was cut to optimise manual handling and its transport off-site. The demolition contractors noted that high-quality furniture, doors, and windows are routinely extracted from buildings but there is currently no resale market in Finland, so all wood material is cut to optimise site removal. Timber elements are not typically checked for distortion, checks, fissures, cracks, or cavities [29]. Most wooden material is broken-down on site to optimise removal; however, timber pallets (packaging) are regularly recovered for repair and reuse.

3.4.2. Germany

In Germany, the total waste wood volume amounts to 6.6 Million t yearly [14]. Wood from demolition in one waste management facility recorded 500 t of Grade **AI** (untreated), 2,000 t of Grade **AII** (glued/ painted), and 400 t of Grade **AIV** (contaminated wood) timber waste per annum. This comprised 30% each of sawn timber and particleboard, 15% furniture, 10% mass timber, and 5% each of doors and windows, door and window frames, and wood-based insulation. A particleboard manufacturer recycles 20,000 t of particleboard, 77,000 t of timber pallets and 60,000 t of Grade **AI** and **AII** wood chip mix per annum.

3.4.3. Ireland

The building and demolition industry accounted for 20,500 t of wood waste in Ireland in 2018 [15], with 38% of the total originating from the greater Dublin area. As construction in Ireland is mainly masonry, timber from demolition is predominately from the roof structure. A multi-storey office block might yield up to 30 t of timber waste. Timber that is treated with carbonaceous chemicals and composite panels are separated from general timber waste for sorting offsite and appropriate disposal. Older larger beams, glulam (uncommon) and solid wood flooring have an intrinsic value and are commonly salvaged for resale. No other wood-waste separation is made on site with respect to wood type (e.g. hardwood, softwood, ply, or particleboard), surface coating, or chemical treatment. Timber elements are not typically checked for distortion, checks, fissures, cracks, or cavities. Most wooden material is broken-down on site to optimise removal; however, timber pallets (packaging) are regularly recovered for repair and reuse.

The typical timber range extracted from demolition in Ireland includes:

- Sawn timber (roof rafters, purlins, wall plates, roof joists, and floor joists):
  38 - 75 mm x 100 - 225 mm in 4 - 5 m lengths
- Internal doorframes:
  Profiled section 44 - 65 mm x 100 - 150 mm in 2 - 3 m lengths
- Handrails:
  Profiled section 25 - 60 mm x 40 - 60 mm in 2 - 3 m lengths
- Wall and ceiling studs:
  25 - 50 mm x 50 - 75 mm in 2 - 3 m lengths
- Skirting boards, window boards, and architraves:
  Profiled section 12 - 18 mm x 75 - 150 mm in 2 - 5 m lengths

- Solid wood flooring:
  18 - 25 mm x 125 - 200 mm in 2.4 m lengths
- Packaging, generally timber pallets:
  16 - 25 mm x 95 - 145 mm in 0.7 - 2 m lengths
- Domestic and office furniture (desks, kitchen cupboards, bedframes, and wardrobes):
  12 - 50 mm x up to 2 m lengths.

3.4.4. Slovenia

In 2013, 350,000 t of timber waste was produced in Slovenia. Of the 53% of the total was used for energy production [16].

3.4.5. Spain

Timber from demolition in Spain including some timber-waste imported locally along the border from France generally comprises old oak and pine elements that are rarely treated. Any distortion, checks, and cavities are noted. Wood-salvage is sorted and stored separately during and after demolition. The timber range extracted from demolition in Spain includes:

- Large timber beams, rafters, and joisting extracted from 100 - 200-year-old buildings:
  120 - 250 mm x 120 - 300 mm sections in 2.5 - 6 m lengths
- Solid wood doors, windows, shutters, painted and unpainted
  Up to 2m lengths
- Solid wood floorboards:
  25 mm x 125 - 200 mm sections.

It was reported that the removal of such material is relatively uncomplicated. Other general non-hazardous Spanish building and demolition timber-waste (**170201**) and one demolition contractor reported that 75% of this structural timber extracted was of a good condition. It generally comprises:

- Sawn timber, doors and windows, door and window frames, furniture, floorboards, particleboard, and timber pallets:
  150 - 200 mm x 150 - 200 mm up to 2.7 m lengths which are generally cut to ease manual handling and removal.

3.4.6. Sweden

Wood-salvage from construction and demolition in Sweden comprises glulam beams, doors and windows, particle board, furniture, floorboards, timber pallets, and door and window frames. Glulam beams and doors and windows were reported be of moderate difficulty to recover, while sawn timber and timber insulation products were reported to be especially difficult to salvage. One waste sorting facility reported processing circa 4500 t of mixed wood, 650 t clean wood, and 200 t of impregnated timber per annum. Another collection site recorded almost 9000 t of mixed wood, 1000 t of impregnated wood, and 50 t of pallets in 2019.

3.4.7. UK

Building and demolition timber-waste in the UK includes sawn timber, mass timber (small amounts), doors and windows, door and window frames, furniture, floorboards, particleboard, pallets, and MDF. One recycling facility recorded 400,000 t non-hazardous wood-waste processed per annum, comprising 30% **Grade A+** (dust free solid clean wood, suitable for horse bedding) and **Grade A** (suited to general animal bedding), with the remaining 70% comprising **Grade B** and **C**. Another facility, recorded processing circa 300 t per week of **Grade A** (50%) and **Grade B** and **C** (50%) from construction, demolition, and civic amenities, which was mixed on-site. Scaffolding boards and whiskey barrels comprised up to 400 t and 100 t per annum, respectively in one salvage yard in Glasgow. Metal content is removed manually. Timber pallets (packaging) are routinely recovered for repair and reuse.

It was observed at one demolition site in the UK of a contemporary structure, that only internal door frames were removed in advance of the main demolition, as to separate the frames later post-disassembly was deemed to be too labour intensive. The remainder of timber was demolished mechanically along with rest of the building fabric.

A total of 4.5 million t of wood waste is generated in the UK per year [17]. Figure 8 outlines the flow of this timber waste currently in the UK.

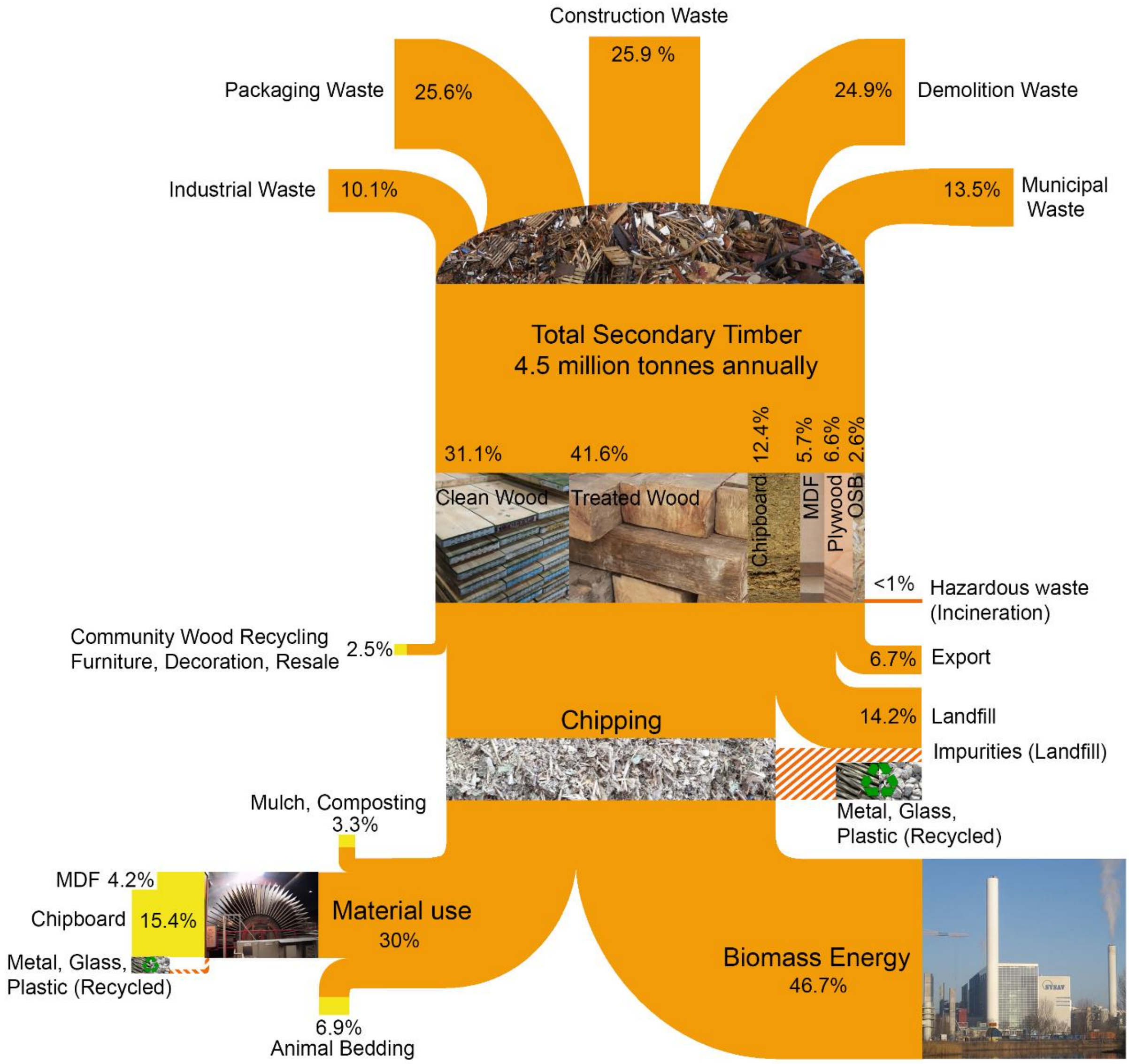

Figure 8: UK timber waste flow diagram (Marlene Cramer, Napier)

Biomass energy production is the primary end-use of the UKs secondary timber. However, the supply of wood waste is less than its demand for biomass energy. In 2018 an additional, 7.8 million t of timber pellets were imported for incineration [18] and 0.8 million t of sawmill residues and 2.2 million t of virgin roundwood [19] went towards biomass energy production. The total UK roundwood production in the same year was 11.5 million tonnes [19].

In summary, based on the review of demolition practices in each of the participating countries, nearly all timber waste from construction and deconstruction is cut and mixed, then subsequently reduced to woodchip. An exception is in the case of large, old (+100-year-old) structural elements and mass-timber products. The following section outlines the scope of reuse of building timber, which will include responses from recycling and wood-salvage facilities.

4. The current scope of timber reuse and recycling

Apart from reuse of old timber in Spain, mass-timber in Sweden, and timber from disused transport infrastructure in the UK, most timber extracted from construction and demolition across the surveyed regions is reduced to woodchip, regardless the size or quality of the extracted material**.** The chip size and non-timber content limit its end-use. Germany accept only untreated timber for particleboard manufacture for instance. The manufacturing process is also subject to local regulation. High-speed shredders are prohibited in England, for example, but are permitted in Scotland.

The wood-chipping process comprises some or all the following measures:

- Excavator sorting: Removing all discernable non-timber elements, including concrete, masonry, stone, metals, glass, and plastics.
- Pre-shredding: Reducing all waste to ≤ 400 mm size
- Air-density separator: Segregating low- and high-density material
- Magnets: Removing ferrous materials
- Manual separation: Removing smaller aggregate, metal, and plastic elements
- Shredding with magnets: Producing a standard sized product, while removing any remaining ferrous material
- Screening: Segregating elements by size, 12, 30, 50, or 60 mm
- Eddy current: Removing non-ferrous metals
- Final chips: The wood-chip size varies up to 60 mm particle size, depending its purpose.
- Wood fines: Fine dust waste from woodchip processing.

Figures 9, 10, and 11 show the timber-waste on arrival at the waste processing facility, pre-shredding and separation, and the screened woodchip product, respectively. Figure 12 shows timber fines, which is a waste by-product of woodchip production.

Figure 9: Timber waste at Fassaroe, Co. Wicklow, Ireland (Image by Daniel F. Llana)

Figure 10: Initial pre-shedding and separating in Roscommon, Ireland (Image by Daniel F. Llana)

Figure 11: Wood-chipping at Fassaroe, Co. Wicklow, Ireland (Image by Daniel F. Llana)

Figure 12 Timber fines at OCR Co. Roscommon, Ireland (Image by Daniel F. Llana)

The following outlines the typical range of collected wood-waste and its current uses in the different countries surveyed.

4.1. Finland

In Finland, construction and demolition waste comprised 14% (15 million tonnes) of total waste in 2015 [13]. Except for soil and mineral waste, wood, metals, glass, and plastic are amongst main material arising from construction and demolition waste [13]. The timber extracted from building and demolition in Finland comprises treated and untreated hardwood and softwood, including oxidized wooden frames, painted, varnished, and oil-waxed wood products of a variety of sizes. It is all mixed and broken, as illustrated in Figure 13. In Finland, the proportion of contaminated wood waste (grade D) that is extracted from construction and demolition sites is small in comparison to clean wood waste (Grades B & C). Not all the recycling facilities accept the contaminated wood waste, though some might accept, and only segregate it to be delivered to other facilities. The clean wood waste is generally sorted (by excavator or NIR Machinery) and shredded in the recycling facilities to be cleaned from contaminations such as metals and plastics using magnets, air sorting and sieving. Small numbers of small metal nails, screws, and hinges are not removed. While it is possible to separate different elements using infrared (NIR) machinery, this is commonly considered too costly.

Most wood-waste is reduced to woodchip for biomass energy production in Finland. A small portion of clean wood-waste is used for other purposes such as in composting and in the manufacture of a composite eco-engineered stone paving to reduce the carbon footprint of the paving. Some wood-waste is exported to Latvia and Poland to produce recycled wood panels, but the priority is given to locally burn the wood-waste for energy recovery. Considering that 9.2 million m^3 of wood-based panels, including particleboard, fibreboard, plywood, and veneers, were produced in Poland in 2014 [20] a market such as this has the potential to be significant for the recycling of wood waste. The clean wood waste used for other purposes than energy recovery needs further cleaning to be suitable for compositing and manufacturing of composites and particleboards. Currently, manufacturers of wood products in Finland do not accept chips from recycling facilities due to the presence of metal contaminations.

Timber pallets are routinely recycled and repaired for reuse in Finland (Figure 14). One facility recorded 500,000 units per annum.

__Figure 13: Timber-waste in Tampere, Finland (Image by Chiara Piccardo, 2019, courtesy of Bahareh Nasiri, Aalto)__

__Figure 14: Timber pallets for recycling in Kerava, Finland (Image by Chiara Piccardo, 2019, courtesy of Bahareh Nasiri, Aalto)__

4.2. Germany

In Germany, the total waste wood volume amounts to 6.6 million t yearly [21]. German wood-salvage is mostly classified in category AI-AIV, defined in Section 3.3.6. According to the German Waste Wood Ordinance, wood from category AI and AII (comprising processed timber, particleboard, pallets, and/or bonded or coated timber) may be used in further material applications. The most common use of recovered wood in recycling applications is in particleboard. The share of recovered wood used to produce particleboard differs between the manufacturers and amounts up to 30 % [14]. The total share of recovered wood used in particleboards in Germany represents only about a third of the total waste wood volume [21]. It is a legal requirement that information on the manufacturer of the wood-product and any chemical treatment of the timber is made available to the recycling facility. Recovered wood that contains halogenated organic compounds in the coatings are classified in category A III, while wood treated with wood preservatives are classified as A IV (sleepers, masts, vine poles, most construction wood). Although use of class A III wood is legally possible if the wood is cleaned of the coatings, it is currently not in practice. Fines too small for material recycling as well as wood from category A IV must be incinerated [11]. Overall, in Germany, two thirds of the total waste wood volume is incinerated [21]. In Germany, most of the recovered wood is traded by large companies. Circa 160,000 t per annum of Grade AI - AII timber is used to produce particleboard at one recycling facility.

The use of recovered wood for furniture or other interior application is limited to small companies and workshops with a rather decorative and individual furniture production, than an industrial approach. Apart from that, hardware stores offer recovered wood beams or boards for DIY projects and decoration as well as flooring boards from recovered wood. Given the recovery and processing efforts, the retail price for the material is high compared to primary timber, which underlines its purpose for individual and decorative projects.

4.3. Ireland

Non-hazardous mixed timber comprises the main body of the timber that is extracted from Irish construction and demolition sites. It is a broken assembly, including clean or painted, structural timbers, doors, doorframes, architraves, skirting and window boards, furniture, and wood-packaging (not including MDF and laminate flooring), that is used to produce woodchip. The value of wood-waste chips is comparable to that sourced from virgin timber. Its end-applications include:

- Pallet blocks: 80,000 t per annum, of mixed woodchips, combined with virgin wood (20,000 t per annum) produce timber-engineered pallet blocks at Eirebloc, Co. Cork. The base wood supply is further screened for non-timber material, hammer milled to 8 mm and dried to 1% moisture content. 50% of the wood-waste intake is sourced from timber pallets and other wood packaging.
  Up to 50 mm particle size is used and MDF may comprise up to 8% of the total mix.

The engineered timber blocks are used in the manufacture and repair of timber pallets. Up to 85% of the product is exported, comprising 40% to the UK, 40% elsewhere in the EU, and 5% to the US and Canada. There are approximately 450 million new pallets made in the EU each year.

- The pre-screening and manufacturing at Eirebloc produce circa 8% waste. This material is further recycled as compost and for landfill cover, with any residual metal content recycled off-site.
- Energy production (industrial): circa 50,500 t per annum, most of the remaining mixed woodchip, is exported to the UK (PAS 111 Grade C) to a large-scale biomass energy plant at CHP (Combined Heat and Power), Lisahally, Co. Derry, Northern Ireland, UK. There is a size requirement for the chip product of between 12 and 30 mm.

Some facilities process only clean, untreated building timber, with offcuts from carpentry or joinery, wood packaging, combined with virgin forest wood-waste. Its end-applications include:

- Pallet blocks: 20,000 t per annum, virgin forest wood, combined with mixed woodchip.
- Compost: 15,000 t per annum, combined with other organic waste material.
- Energy production (domestic): 3,000 t per annum, produce fire logs suitable for domestic stoves.
- Energy production: In-house off-cuts combined with forest wood bark is used as boiler fuel in many wood processing facilities.

Only wood-waste (up to 50 mm) that is completely clean of any chemical treatment or coating is suitable for:

- Garden mulch,
- Playground surfaces, and — 1,000 t per annum
- Animal bedding.
- Wood-based panel manufacture: 1,500 t per annum.

Reuse: Timber pallets are universally salvaged for collection (over 10,000 t per annum). This includes broken units which are repaired. In some instances, there is a levy for pallet deliveries without a return pallet. Solid wood flooring may be salvaged for resale; however, laminate wood flooring is regarded as general waste. A small proportion of roof or joist members are reused, un-broken, for agricultural building or farm fencing, without certification. One architectural salvage facility in Dublin, repairs and makes new furniture and even musical instruments with some of the wood stock.

4.4. Spain

100-200-year-old oak, pine, and sweet chestnut structural members are salvaged for resale, circa 600 t of wood-salvage per of annum was recorded by one contractor. The rural, urban ratio around 5:1. Other general non-hazardous building and demolition wood waste (**170201**) is broken and reduced to woodchip to produce particleboard (80%), with the remainder used in biomass energy and compost production in Spain. Timber pallets are salvaged whole for repair (if necessary) and reused. One waste management facility reported processing 7000 t and 1000 t of timber waste per annum from demolition and carpentry, respectively, with a further 2000 t from forest thinning and pruning and 500 t of furniture and timber pallets. 80% of their product is used in particleboard manufacture, with the remainder consumed in energy production. Another facility recorded processing 2,000 t (comprising mainly sawn timber) and 50,000 t per annum from demolition and wood manufacturing, respectively. The timber-waste was reduced to woodchip for particleboard, biomass, and for compost.

4.5. Sweden

Typical timber-waste extracted by one demolition contractor from Swedish sites in one year included:

- Mass-timber (glulam beams), 312 t of which 90% of wood was salvaged for reuse,
- Doors, windows 76 t of which 20% was salvaged,
- Furniture 54 t of which 5% was salvaged, and
- Timber pallets 15 t of which 100% was salvaged.

Also extracted were 16 t of door and window frames, 32 t of floorboards, and 72 t of particleboard; however, 0% wood was recovered from these products in this case.

4.6. UK

Non-hazardous demolition timber-waste material is generally shredded and chipped collectively, with impurities removed using magnets, air sorting and sieving at the recycling facilities as outlined above. The end-use of woodchip is determined by its base timber product. One waste sorting facility recorded circa 30% of woodchip to be of clean wood base (**Grade A+** and **A**) and suited to animal bedding and mulch. Circa 35% was used in particleboard manufacture (**Grade A** and **B**), with 35-50% consumed for energy production (**Grade B** and **C**), and the remainder repurposed in compost. Another wood processing facility recorded processing 75% woodchips and fines in particleboard and 25% woodchip (**Grade C**) towards biomass.

Wood-salvage for reuse includes scaffolding boards, furniture, floorboards, particleboard, sawmill rejects, plywood, wood packaging and whiskey barrels, shown in Figures 15, 16, and 17. Treated timber is resold for garden sheds and furniture. The two facilities produce furniture with a portion of the wood-salvage on a small scale. In times when the storage capacity is exhausted, all surplus timber waste is converted to woodchip for biomass energy production.

Wooden pallets are routinely collected for repair and reuse, and the industry estimates that 46 million wooden pallets were inspected and repaired in the market during 2018, which is slightly more than the number of new pallets produced.

Figure 15: Wood-salvage, UK (Image courtesy of Marlene Cramer, Napier)

Figure 16: Structural wood-salvage with grade and nails in Glasgow, UK (Image courtesy of Dan Ridley-Ellis, Napier)

Figure 17: Scaffold boards salvaged in Glasgow, UK (Image courtesy of Dan Ridley-Ellis, Napier)

5. Potential for secondary use and recycling of recovered timber

As outlined in the previous chapter, much of the timber recovered during demolition is reduced to chips for use in particle board manufacture or for the generation of bioenergy. Particle board is a very common construction product and using recovered timber in the production reduces the demand for virgin wood. Nevertheless, solid wood cascade uses should be considered before the material is broken down into chip form. The following outlines the potential alternative reuse of typical wood-waste that is collected at present in the different countries surveyed.

5.1. Older structural beams

Older beams of a large cross-section, shown in Figure 18, are a common material recovered from demolition in Spain and to a lesser extent in other partner countries. The wood is usually oak, pine, or sweet chestnut. These structural elements are generally in the range of 120 - 250 mm by 120 - 300 m, and up to 6 m lengths. The wood is usually uncoated.

Figure 18: Timber salvage for resale in Dublin (Image by Caitríona Uí Chúláin, NUIG)

The size of the members and the wood type facilitates many second-life uses and studies have found that such material has dimensional stability, acquired from prolonged conditioning [22]. Potential secondary uses include:

- Furniture and internal joinery fit-out: This type of wood-salvage is generally regarded to be very suited to this purpose as even cracks, fissures, holes, and decay can be considered of aesthetic merit, provided the wood is appropriately treated before use.
- Structural beams, joists, and columns: The typical member size salvaged is suitable for structural use, but the absence of certification is a limiting factor. Possible decay or fungal attack along with checks, cracks, fissures, and holes, all may reduce the material integrity of the wood.
- CLT and glulam: While there is sufficient scope in the size of the base material and cracks, holes, and decay can be finger jointed out in manufacture, a material with such coveted aesthetic appeal might be best used for the external exposed lamina. However, the sourcing of an adequate supply of a similar visual grade may be problematic and the European Standard EN16351 does not allow the use of secondary timber in the production of CLT. This wood-salvage is equally suited to glulam manufacture, depending on the strength and stiffness grade of the base wood. This is assuming there is no incompatible treatment of the base wood.
- Timber veneer: A reuse at the end of the cascade use of the timber salvage. A deterrent to manufacturers may be the potential for metal content in the base material and a limited supply of one visual grade. Also, research is required to investigate the suitability of older timber for veneer production.
- Woodchip: Although large structural beams and columns are suitable for particleboard and wood-fibre insulation, other cascade uses might improve its overall life cycle.

5.2. Sawn structural timber sections

Roof, ceiling, and floor sawn timber are universally extracted from demolition and comprise softwood members with cross sections ranging from 38 - 75 mm by 150 - 225 mm, and up to 5 m lengths. The typical base material size gives ample scope for repurposing and are of a size suited to manual handling, which increases the potential for salvage during deconstruction [23]. The standardization of dimensions and grading lend well to its reuse, but a significant limitation to the secondary use is the potential content of toxic preservatives [24].

- Reused structurally: The main limitation on reusing timber structurally is the absence of structural certification. Possible decay or fungal attack along with checks, cracks, fissures, and holes, all may reduce the material integrity of the wood.
- CLT and glulam: Life cycle assessment and costing studies in Germany found that reusing timber in glulam products was economically viable. The study showed environmental and economic benefits over the current practice of reducing to wood-chip for incineration [25]. The base member sizes of standard sawn wood are sufficient for CLT manufacture (20 - 40 mm by 40 - 150 mm base boards. While the extent of metal content in the wood-salvage could be a significant deterrent to manufacturers,

it has been shown that an efficient method of removing metal content for CLT manufacture was to cut wood-salvage to standard sizes. It was determined that a lamina size for reclaimed timber of 20 x 60 mm is an optimal balance between useable timber size member, lamina yield, and off-cut waste, estimating that a yield of 30% of the initial wood-salvage was possible [26][27].

- Internal door frames: There is sufficient scope in the size of the base material for most standard doorframes (Profiled section 44 - 65 mm x 100 - 150 mm); however, potential metal content is again a possible disincentive.
- Laminated and half-solid internal doors: The internal structure of engineered doors comprise solid-wood infill (circa 40 mm x 125 mm boards). Repurposed softwood, if not damaged by decay of fungal attack may be used.
- Stairs, handrails, and balustrades: Sawn timber members sizes are of a sufficient cross-section for repurposing in stairways (Profiled section 25 - 60 mm x 40 - 60 mm) in standard grade joinery that is usually painted. Possible decay or fungal attack along with cracks, fissures, and holes, may reduce the materials structural integrity.
- Landscaping: This type of wood-salvage can be regarded as very suited to external decking, planters, edging, and fencing posts. One respondent in the UK repurpose treated sawn timber in outdoor applications.

5.3. Mass-timber

The recovery rate is high for mass-timber.

- Reused structurally: Certification is the main limitation on reusing timber structurally. Possible decay or damage may reduce the materials structural integrity. Degrading of connections or of lifting eyes are key pressure points. But in general, large modular sections which can be extracted in one piece are preferable to smaller elements with a range of different components.

5.4. Internal joinery

Internal joinery encompasses a wide range of timber types and sizes, including hardwood and softwood doorframes, architraves, skirting and window boards, stairs, balustrades, and handrails, with a cross section ranging from 18 - 65 mm by 45 - 150 mm, and over 2 m lengths. Figure 19 shows a sample pile of standard-size joinery from the top-down demolition of a multi-storey office building.

Figure 19: Internal joinery stacked for removal in Dublin, Ireland. Image by Daniel F. Llana

Some possible second-life applications include:

- Reused: Handrails and stair balustrades, skirting boards, window boards, and architraves may be reused as initially intended; however, coatings and metal content may prove a deterrent. Good quality hardwood members may be suitable for renovation or for a particular aesthetic.
- Internal trimming boards: Larger elements (e.g. large architraves, window boards, and skirting boards) can be reduced to standard-size architraves, window boards, and skirting boards and for decorative painted edging such as dado-rails and wainscotting.

It is generally agreed that doorframes are especially difficult to extract during demolition and are commonly coated, with integrated fire and sound strips in modern frames and are therefore difficult to repurpose.

5.5. Timber flooring

Hardwood and softwood boards with cross section ranging from 18 - 25 mm by 125 - 200 mm, and up to 2.4 m lengths.

- Reused: The simplest and most conventional repurpose is as flooring, which allows for multiple cascade use.
- CLT manufacture: There is sufficient capacity in the base material (20 - 40 mm x 40 - 150 mm); however, the extent of metal content could be a deterrent to manufacturers. Any chemical treatment incompatible with the CLT adhesives and the strength and

stiffness grade of the base wood, must also be considered. Out-of-grade timber may prove sufficient for internal CLT lamina [28].

- Wall cladding: Solid wood flooring is of an adequate dimension for repurposing as internal panelling or external wall cladding (Profiled section 15 - 22 mm x 125 mm), depending on the timber type and treatment. Sourcing an adequate supply of a similar visual grade may be problematic.
- architraves, skirting and window boards: Wood flooring may be repurposed for standard internal joinery.

5.6. Wall and ceiling studding

Wall and ceiling timber grounds are a common source of wood-waste yield from demolition. The elements are usually softwood with a cross section ranging from 25 - 50 mm by 50 - 75 mm, and up to 3 m lengths.

- The larger studding members may be reused in the same way as structural timber or solid floorboards.

5.7. Domestic and office furniture

The size range and wood type that makes up the stock of internal furniture is substantial.

- Reused: A recycling facility in Dublin, Ireland have reused furniture timber in room partitions (portable screens), newly design furniture and for musical instruments; however, probably the most efficient reuse is to repair and reuse as initially intended.

5.8. Timber packaging

Timber packaging comprises a wide size range of softwood and particleboard sections, with the most standard elements, making- up timber pallets, range between 16 - 25 mm by 95 - 145 mm, and up to 2 m lengths.

- Reused: Timber pallets are universally reclaimed, repaired, and reused, with broken pallets used in agriculture, playground surfaces, animal bedding, and wood panel board manufacture. Figure 20 shows sorting of pallets for reuse from the general timber waste which is to be reduced to woodchip. The general timber waste pile includes a significant amount of sawn timber from construction and demolition; however, respondents consistently stated that unlike pallets, there is currently no alternative market for its reuse. In the UK, the recovery of pallets is incentivised by the government with Packaging Recovery Notes, that make their repair and reuse profitable.

Figure 20: Timber pallets are sorted from the general timber-waste at Fassaroe, Co. Wicklow, Ireland (Image by Daniel F. Llana)

6. Conclusions

Currently most timber extracted from building demolition is broken to minimise the cost of removal and is subsequently reduced to woodchip for the manufacture of timber-engineered pallet blocks, biomass energy production, or for particleboard production and agricultural use where it is appropriately uncontaminated. The demand for woodchip is high and sustained; however, building timber may have other cascading applications before its end-of-life. The cost of disposal is always compared against its potential worth and while site storage is generally limited, materials are routinely separated and stacked for collection if there is sufficient profit to be made from its recovery (e.g. clean solid timber of large cross-section and length) or where there exists a reliable route to market (e.g. timber pallets). The main reason given by industry for not recovering timber for reuse is a deficiency in market demand.

A key limiting factor preventing the reuse of recovered structural timber is the lack of certification. Suitable grading criteria to establish structural performance of wood-salvage are necessary to facilitate recertification. Additionally, the presence of metal and other impurities such as plastics or minerals in the recovered timber could hinder the processing into new products such as mass-timber and panel products. Chemical treatments may be incompatible with mass-timber adhesion and a record of wood treatment history is not available in most jurisdictions. Also, from a sustainability perspective, chemicals, such as preservatives, should not accumulate in the material flow.

Another disincentive given for the recovery and reuse of building timber is its integration with other materials. In general, products that have been engineered and integrated with other non-wooden elements for a specific purpose (e.g. door and window frames, insulated panels) are not easily deconstructed or separated. Profiled cross-sections that are coated or have adhered sealants can make the dressing back of wood-salvage unviable. Such products are generally assumed to be outdated for reuse at the time of demolition due to ever rising building standards. While building deterioration is a common cause for site clearance, a more significant motivation in urban areas is market value decline and for redevelopment. It may be inferred, therefore, that a product's potential reuse and recycling should be equally prioritised with its lifespan and durability at the manufacturing stage. Essentially the current EU Waste Directive promotes research towards progressing this aim; however, effective cascade use of timber is not yet at optimum.

Large sections, comprising one basic element, are preferable to small multi-element products. Traditional building sections are preferred for salvage over newer composite building components. But modern products can be just as suited to repurposing. As seen in Sweden, 90% of the timber in mass-timber was salvaged and the recovery process of glulam beams was deemed to be of moderate difficulty.

Current policies and regulations also hinder the reuse of timber recovered from demolition or remodelling of buildings. There are currently incentives for biomass energy so there is a financial motivation to burn the material rather than consider other cascade uses. Incentives should also be available for reuse of timber in applications such as construction, which extend the life span of the materials. A rebate or BREEAM credits for reusing materials could incentivise the use of building material salvage. High profile companies may buy-in to promote the green-credentials of their premises. The structural reuse of timber in buildings is also prohibited or limited by regulation. Development of scientific data on the performance of recovered timber and the establishment of grading approaches for its assessment will provide the basis for revisiting these restrictions.

As is illustrated by the timber pallet second-hand trade, standardised products with an established resale market are routinely and universally salvaged for reuse. Therefore, universal standardisation of timber materials, reduced integration with other elements, specifically non-timber components, and minimal chemical treatment can all be regarded as beneficial to improving a more effective cascade use of forest yield.

In conclusion, the basic criteria identified to facilitate the reuse of timber products are:

- A core dimension that is free of decay, coatings, adhesions or metal content, (e.g. min. 38 x 150 mm x 3 m for structural use of sawn timber, 20 x 60 mm boards for CLT, with internal joinery and flooring dimensions varying from a min. 12 x 120 mm cross-section value),
- A strength and stiffness grading standard and subsequent structural certification, and
- A record of the chemical treatments in the wood.

Qualities that incentivise timber reuse are:

- A large cross-section and length from which any coating and metal content can be cut to standard dimensions,
- Untreated timber is suited to a more varied range of reapplications,
- Reduced adhesion, by glue or mechanical connection, with non-timber elements improves its safe extraction and recovery during demolition,
- The provision of optimised mechanical connections, that would result in a reduced metal content in the wood-salvage,
- Reduced chemical treatment of the wood,
- Reduced processing of the timber generally. Untreated beams of a larger cross-section provide a greater potential for multiple cascades of use over smaller and integrated multi-element components.

7. References

[1] European Council, “Directive 2008/98/EC,” *Off. J. Eur. Union*, vol. 56, no. C 378, pp. 1–44, 2013.

[2] TUM, “CAREWOOD Technology development for the reuse of wood and product development,” Munich, 2017.

[3] Hogan, P., Hegarty Demolition Ltd., “Demolition Practices in Ireland.” 2020.

[4] Llana, D.F., Íñiguez-González, G., de Arana-Fernández, M., Uí Chúláin, C., Harte, A.M., Recovered wood as raw material for structural timber products. Characteristics, situation and study cases: Ireland and Spain, in *Proc. Society of Wood Science and Technology International Convention*, Jul 2020, Portoroz, Slovenia (Virtual).

[5] Hegarty Demolition Ltd, “Long-reach demolition.” http://www.hegartydemolition.ie/projects/ (accessed Oct. 16, 2020).

[6] ISO/TC 218, *ISO/DIS 17300-1 Wood residue and post-consumer wood-Classification*. 2019.

[7] European Commission, "Commission notice on technical guidance on the classification of waste", 2018/C 124/01, OJEU, Brussels, 2018.

[8] Enviromental Protection Agency, *List of Waste & Determining if Waste is Hazardous or Non-hazardous.*, Johnstown Castle, Co Wexford Ireland, July. 2015.

[9] Alakangas, E., Koponen, K., Sokka, L. Keränen, J.T. and Keränen, J., “Classification of used wood to biomass fuel or solid recycled fuel and cascading use in Finland (VVT),” 2015, [Online]. Available: https://www.researchgate.net/publication/281620183.

[10] Garcia C.A. and Hora, G., “State-of-the-art of waste wood supply chain in Germany and selected European countries,” *Waste Manag.*, 70: 189–197, 2017, doi: 10.1016/j.wasman.2017.09.025.

[11] Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (BMUB) (2012) Ordinance on the management of waste wood (Altholzverordnung – AltholzV), Berlin.

[12] British Standards Institution (BSI), *PAS 111 Specification for the requirements and test methods for processing waste wood*. 2012.

[13] Liikanen, M., Havukainen, J., Grönman, K. and Horttanainen, M., 2019. Construction and demolition waste streams from the material recovery point of view: A case study of the South Karelia region, Finland. *Waste Management and the Environment IX*, *231*, p.171.

[14] Meinlschmidt, P., Mauruschat, D., Briesemeister, R. (2016) Altholzsituation in Europa und Deutschland. *Chem. Ing. Tech*. 88 (4): 475-482.

[15] NSAI, “National Waste Collection Permit Office (NWCPO),” 2018. https://www.nwcpo.ie (accessed Sep. 17, 2020).

[16] The Statistical Office of the Republic of Slovenia, “190,000 tons of generated wood waste used for energy purposes,” 2015. https://www.stat.si/StatWeb/News/Index/5197 (accessed Nov. 05, 2020).

[17] Michaud, J.-C., Farrant, L. Jan, O., Kjær, B. and Bakas, I., “Environmental benefits of recycling - 2010 update,” *Waste Resour. action Program. WRAP*, no. March, pp. 1–252, 2010, [Online]. Available: http://www.wrap.org.uk/sites/files/wrap/Environmental_benefits_of_recycling_2010_update.3b174d59.8816.pdf.

[18] Office for National Statistics UK, “A burning issue: biomass is the biggest source of renewable energy consumed in the UK,” 2019. https://www.ons.gov.uk/economy/environmentalaccounts/articles/aburningissuebiomassisthebiggestsourceofrenewableenergyconsumedintheuk/2019-08-30 (accessed Nov. 05, 2020).

[19] The Forestry Commission UK, “Forestry Statistics 2018. Chapter 3: Trade,” no. September, p. 14, 2018.

[20] Kobuszynska M. and Nicely, R., “Gain Report: Forestry and Wood Products in Poland,” Warsaw, 2017.

[21] Mantau, U., Döring, P., Weimar, H., Glasenapp, S. (2018) Rohstoffmonitoring Holz. Mengenmäßige Erfassung und Bilanzierung der Holzverwendung in Deutschland. Schriftenreihe Nachwachsende Rohstoffe 38, Gülzow-Prüzen, 161 pp.

[22] Brol, J., Dawczy, S. and Adamczyk, K., “Possibilities of timber structural members reuse,” *3rd Int. Conf. Struct. Heal. Assess. Timber Struct.*, no. December, pp. 1–7, 2015.

[23] Cheshire, D., *Building Revolutions. Applying the circular economy to the built environment*. RIBA Publishing, 2016.

[24] Hafner, A. Ott, S. and Winter, S., “Recycling and end-of-life scenarios for timber structures: Materials and Joints in Timber Structures,” *RILEM Bookseries*, 9: 89–98, 2014, doi: 10.1007/978-94-007-7811-5.

[25] Risse, M. Weber-Blaschke, G., and Richter, K., “Eco-efficiency analysis of recycling recovered solid wood from construction into laminated timber products,” *Sci. Total Environ.*, 661: 107–119, 2019, doi: 10.1016/j.scitotenv.2019.01.117.

[26] Irle M., *et al.*, “Advanced recycling of post-consumer solid wood and MDF,” *Wood Mater. Sci. Eng.*, 14(1): 19–23, 2019, doi: 10.1080/17480272.2018.1427144.

[27] Irle, M. Privat, F. Deroubaix, G. and Belloncle, C., “Intelligent recycling of solid wood,” *Pro Ligno*, 11: 14–20, 2015.

[28] Cherry, R., Manalo, A., Karunasena, W., and Stringer, G., “Out-of-grade sawn pine: A

state-of-the-art review on challenges and new opportunities in cross laminated timber (CLT)," *Constr. Build. Mater.*, 211: 858–868, 2019, doi: 10.1016/j.conbuildmat.2019.03.293.

[29] Nasiri, B., Piccardo, C. and Hughes, M., "Estimating the material stock in wooden residential houses in Finland. " Waste Management, 135, pp.318-326, 2021, doi: https://doi.org/10.1016/j.wasman.2021.09.007.

[30] Nasiri, B., Hughes, M. *et al,* InFutUReWood WP4 report, D4.2: Study current demolition/deconstruction practices. Unpublished report, Aalto University, Finland.

Appendix A: Survey of Wood Waste

This survey form was completed by industry stakeholders in partner countries as part of the work of WP3 and WP4.

Detailed analysis of the results of demolition practices in surveyed countries may be found in the WP4 report, D4.2: Study current demolition/deconstruction practices [30].

Survey of Wood Waste

Declaration of confidentiality
The information you provide will be treated in the strictest confidence. For further details, please read the "Information for Research Participants in Wood Waste Survey" document attached to this survey.

Questions:

This survey is designed for an online or face-to-face interview of companies. The questions in the survey are divided by content into four sections, namely: 1. General, 2. Demolition companies, 3. Waste management, and sorting companies, and 4. Recycling, reusing, and reprocessing companies. The general section is created to clarify which sections from 2 to 4, should be asked from interviewee(s). However, the situation might differ in different countries, so please consider asking all relevant questions according to the business activities. Also, note that some questions are repeated in sections, as they are applicable to more than one kind of company.

1. General

1.1. What are the business activities of your company? How much hazardous and non-hazardous timber waste goes to different activities per year (If applicable)?					
ACTIVITY	YES	NO	Hazardous wood waste (Percentage)	Non-hazardous wood waste (Percentage)	COMMENTS
Demolition of buildings					
Transportation of waste					
Waste sorting					
Recycling of waste					
Reuse of waste					
Energy recovery					
Others (specify):					

2. Demolition companies

2.1. What are the major steps in demolition of buildings? Describe the process, please.

2.2. What methods are generally used in demolition of different building types?						
Building types	Dismantling/Deconstruction (m^2/annum) or (count/annum)*		Mechanical demolition (m2/annum) or (count/annum)*		Others (specify): (m2/annum) or (count/annum)*	
Areas	Urban	Non-urban	Urban	Non-urban	Urban	Non-urban
Loadbearing material						
Wood						
Masonry						
Concrete						
Steel						
Other(specify)						
Intended use						
Detached houses						
Row houses (terraced)						
Blocks of flats						
Blocks of offices						
Retail						
Other(specify)						
*The unit (m^2/annum) is equivalent to the gross floor area of buildings per year. However, if it is not known, specify the number of buildings per year (count/annum).						

2.3. How much building demolition took place for different building types in recent years?			
Building types	If known gross floor area of buildings per year (m^2/annum), if not number of buildings per year (count/annum)	How old are these buildings?	COMMENTS
Intended use			
Detached houses			
Row houses (terraced)			
Blocks of flats			
Blocks of offices			
Retail			
Other(specify) (count in one year)			
Number of storeys			

1-2 storeys			
3-4 storeys			
Above 5 storeys			

2.4. Does the loadbearing material influence the life-time of buildings? If yes, which load-bearing material is most durable? Could you estimate the average life-time?

2.5. What are the most likely reasons for demolition of different building types?									
Building types	Internal-physical factors, like: Maltreatment, overload, misuse -Changed functions, use, occupants behaviour		Internal-behavioural factors, like: Ageing, wear, weathering, fatigue -Poor design/ construction/ maintenance / management		External-physical factors, like: -Impact of nearby construction, traffic, seismic activities etc. -Government regulation, taxation, rising standards, technology, and energy efficiency.		External behavioural factors, like: -Filtering, social deprivation in the neighbourhood, criminality, urban and planners blight, -Depreciation of market value by new technology, changing user preferences, shrinking demand		Other
	YES	NO	YES	NO	YES	NO	YES	NO	
Intended use									
Detached houses									
Row houses (terraced)									
Blocks of flats									
Offices									
Retail									
Comments									

2.6. Which is the typical range of timber products obtained from demolition? And how much timber is recovered of each kind?					
PRODUCT	YES	NO	t/annum	% total wood recovered	COMMENTS
Sawn timber					
Mass timber products (e.g. CLT, Glulam)					
Doors and windows					
Door window frames					
Furniture					
Floor boards					
Particleboard					
Pallets					
Others (specify):					

2.7. Recovered sawn timber information			
ISSUE	PARAMETER	VALUE	COMMENTS
Most common dimensions	Cross-sections	Dimension (mm):	
		(%/building):	
	Lengths (%/building)	2.7 m ≦ L (Large):	
		1 m ≦ L < 2.7 m (Middle):	
		L < 1 m (Small):	
Kind of component	Beam (%/building)		
	Column (%/building)		
	Rafter (%/building)		
	Joist (%/building)		
	Wall studs (%/building)		
	Others (%/building)		
Surface condition* (% of total wood recovered)	Coated1		
	Treated2		
General condition (acceptable or not)	Distortion		
	Checks		
	Holes		
	Others		
Other information:			
1 Superficial treatment (e.g. painted) 2 Internal treatment (e.g. preservatives impregnation)			

2.8. Where is wood waste segregation carried out? (Describe the process)			
PLACE	t/annum	% in each place	COMMENTS
In-situ			
Recycling facility			
Other information:			

2.9. How difficult is to recover and segregate the wood products? (if it is carried out in-situ)					
PRODUCT	So difficult	Difficult	Medium	Easy	COMMENTS
Sawn timber					
Mass timber products (e.g. CLT, Glulam)					
Doors and windows					
Door and window frames					
Cladding					
Floor boards					
Particleboard					
Wood products +insulation					
Others (specify):					

3. Waste management and sorting companies

3.1. What classification system of wood waste is used in your country?						
How materials are split by skips?						
Classification system or standard						
Number of grades						
Specifications for each grade						
% of recovered wood in each grade						
Other information:						

3.2. How much timber waste is obtained from the following industries each year?			
INDUSTRIES	Hazardous wood waste (t/annum)	Non-hazardous wood waste (t/annum)	COMMENTS
Construction			
Renovation			
Demolition			
Wood manufacturers (carpentries…)			
All above industries			
Others (specify):			

3.3. Where is wood waste segregation carried out? (Describe the process)			
PLACE	t/annum	% in each place	COMMENTS
In-situ			
Recycling facility			
Other information:			

3.4. Which is the typical range of timber products obtained from demolition? And how much timber is recovered of each kind?					
PRODUCT	YES	NO	t/annum	% total wood recovered	COMMENTS
Sawn timber					
Mass timber products (e.g. CLT, Glulam)					
Doors and windows					
Door window frames					
Furniture					
Floor boards					
Particleboard					
Pallets					
Others (specify):					

3.5. Recovered sawn timber information			
ISSUE	PARAMETER	VALUE	COMMENTS
Most common dimensions	Cross-sections	Dimension (mm):	
		(%/building):	
	Lengths (%/building)	2.7 m ≦ L (Large):	
		1 m ≦ L < 2.7 m (Middle):	
		L < 1 m (Small):	
Surface condition* (% of total wood recovered)	Coated1		
	Treated2		
Other information			
1 Superficial treatment (e.g. painted) 2 Internal treatment (e.g. preservatives impregnation)			

3.6. Is wood waste imported or exported?	YES		NO	
From where				
To where				
For what purpose				
Other information:				

3.7. What classification system of wood waste is possible to use? Is it possible to define the classification of wood waste by wood products (e.g. structural timber is class B)?

4. Recycling, reusing and reprocessing companies

4.1. How difficult is to recover and segregate the wood products?					
PRODUCT	So difficult	Difficult	Medium	Easy	COMMENTS
Sawn timber					
Mass timber products (e.g. CLT, Glulam)					
Doors and windows					
Door window frames					
Cladding					
Floor boards					
Particleboard					
Wood products +insulation					
Others (specify):					

4.2. What timber waste treatment methods are applied to different wood products obtained from demolition? How much timber recovered of each kind?					
PRODUCT	Recycling (m^3/annum)	Reusing (m^3/annum)	Energy recovery (m^3/annum)	Others (specify): (m^3/annum)	Possible second-life applications or products
Sawn timber					
Mass timber products (e.g. CLT, Glulam)					
Cladding					
Doors and windows					
Door, window frames					
Furniture					
Floor boards					
Particleboard					
Others (specify):					

4.3. What is the current reuse or recycling of wood?							
USE	YES	NO	m^3/annum	% of each kind	Kind of product	Manufacturer	Comments
Structural							
Furniture							
Particleboard							
Pallets blocks							
Energy production							
Composting							
Landfill							
Others (specify):							

4.4. Is there any information associated with recovered wood from the original manufacturing?	YES		NO	X
Manufacturer				
Species				
Treatments				
Grading system				
Grade				
Other information:				

4.5. Potential products where recovered wood can be used			
PRODUCT	YES	NO	COMMENTS
CLT			
Glulam			
Particleboard			
Pallets			
Others (specify):			