Recycling and End-of-Life scenarios for timber structures

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Abstract

In consideration of sustainable buildings, closing life cycle loops becomes more and more important. Up to now reuse and recycling is taken rarely into account in building processes. With rising consumption of wood for energetic use recycling of material becomes more important.
Up to now there are various studies in EU market ([1], [2], [3]) which quantify the usage of wood in market shares. Explicit calculations on recycling of wooden material in the building sector have not yet been done. In general the demand for reclaimed wood products in the building sector will rise due to the fact that the thermal use of wood is the last option in the cascade of use. The preferred option has to be the reuse and the recycling of reclaimed wood. On this option the refinement of reclaimed wood for innovative products as well as the broadening and enhancement of the cascades of reuse and recycling is strongly needed for the timber construction industry. Long-term and resource efficient use of wood from premium quality (like laminated wood, plywood, timber frame construction) is necessary to ensure sustainable construction with wood. In the process of planning wooden construction the deconstruction and reuse / recycling of the products has to be considered too.
This article also shows different recycling scenarios for waste wood management due to the contamination problem of particular fractions. The different waste wood fractions in strength, scale and size will tolerate certain processing options with an emerging range of recycling products.
Aim is a realistic estimation of theoretical scenarios for end of life and their influence on planning processes as well as the influence on life cycle assessment according to EN 15978. In this paper outcomes of the woodwisdom-net research project ECO2– wood in carbon efficient construction – as well as calculations on wood consumption of wide-span timber structures and investigated case studies on a very detailed level are brought together to show the state of art and theories to improve resource efficient usage of wood. In another approach the total demolition of an old wooden house in the Alps was evaluated. It is a typical example for a long-used construction with numerous repair intervals, changes, and additions. This leads to a wide variety of fractions and often to a contamination of wood from preservatives. The fractions of the demolished house mainly consist of small bits and pieces dedicated to different recycling options than wide span structures. The different waste wood fractions in strength, scale, and size will tolerate certain processing options with an emerging range of recycling products.
A better management of its renewable resources supports the material supply of the wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preservation and also gain market shares now and in the future.

Keywords: Life cycle; end of life; reuse; recycling; timber structures; ECO2-project

1. Introduction

With a growing importance of wood as significant biomass component of the renewable energy supply, there might be a shortage in the availability of wood in the future [4]. The European Commission therefore proposed inter alia to increase the efficiency in the production and the use of wood. [5] A better management of its renewable resources helps the wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preserving and also gaining market shares now and in the future. Solid and glued wood products should have the chance of a second, similar product life instead of recycling without preservation of solid wood properties. Today's most important challenge is to activate the potential of the wood sector to provide construction products fulfilling these requirements.

In consideration of sustainable buildings closing life cycle loops becomes more and more important. Up to now reuse and recycling of existing buildings are not examined widely. Reuse and recycling is taken rarely into account in building processes which is centred on the production, erection and operation of constructions. There is a lack of competitiveness of products within the forest-wood chain concerning the end-of-life strategies. The advantage of wood as a carbon storage can be obtained through reuse and recycling of the material. Only after all options of recycling are exploited the additional advantage of energy recovery should be used. This has a positive effect, which will lead to improved lifecycle assessment (LCA) indicators for wood based products. Finally the production and use phase of existing wood based products can be improved by consequently enhancing the cascades of utilisation.
On the other hand there is a clear need for a life cycle oriented observation of constructions. This includes the dismantling and end-of-life of the buildings. This paper shows the state of art and theories to improve resource efficient usage of wood. A better management of its renewable resources can help the material wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preservation and also gain market shares now and in the future.
With rising consumption of wood as renewable energy source recycling of material becomes more important.

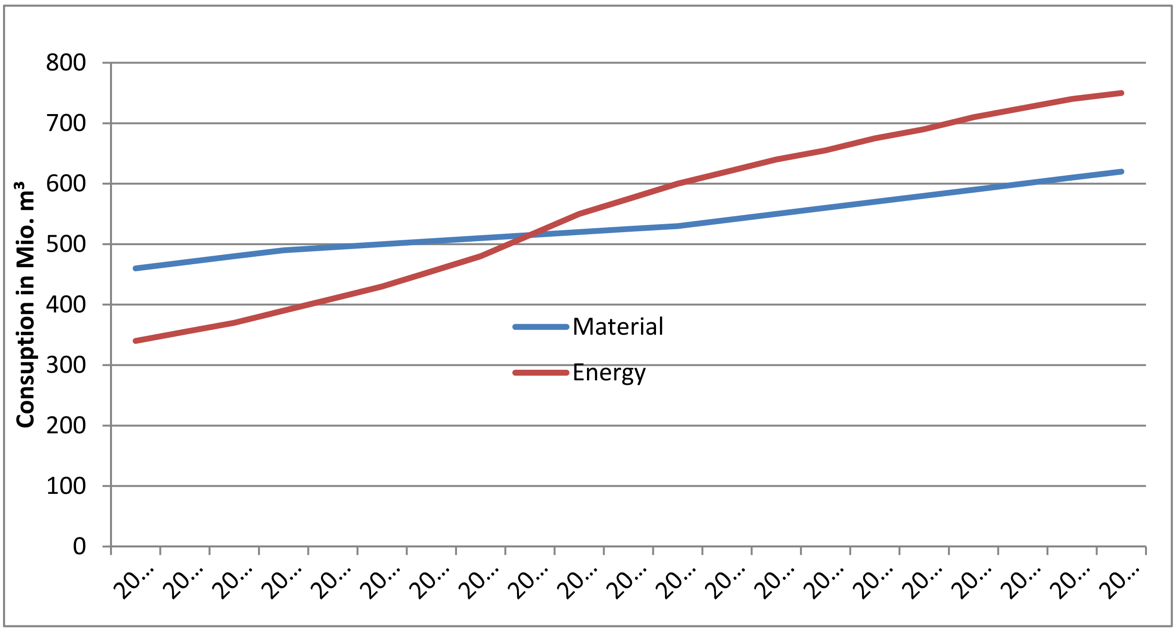

Fig. 1: Consumption of wood for energetic and material use in Europe [6]

As shown in [6] the consumption of wood for material use will rise slowly in the future, whereas the consumption of wood for energetic use will rise dramatically. In Germany wood for energetic use already exceeds the material use in 2012, five to six years earlier as actual calculations from Mantau have predicted in 2010.

This fact causes a rising share of fresh wood thermally used, and a shortage and in long run rising cost for raw material supply of the timber construction sector. The use of good quality, recovered wood not only as energy source reduces this economic pressure. Old buildings can provide the necessary dimensions and quantities of wood. Other sources rely on much smaller dimensions and are less useful. The scope of this paper is an estimation of the quantities and qualities of recovered wood. Additionally there are other fractions a building consists of, which are only side products in this study.

Therefore various research was done estimating the amount of usable material for recycling in wooden buildings and wide-span timber structures. On the other hand related outcomes of finished woodwisdom-net project ECO2 – wood in carbon efficient construction are included in this paper.

2. General framework on recycling of wood

The EU Directives as well as the national laws in many European countries aim at a higher rate of re-use and recycling, which leads to reduced amounts of wastes to be landfilled. The basic principle in the European waste management directive is that materials should be primarily recovered for secondary use, and not until a secondary option, they can be utilised as energy. It is evident that burning for energy is not accepted as recycling anymore in the future. The general idea of the legislation is to prevent waste generation, facilitate its utilisation, and reduce the disadvantages caused by waste management. Materials can be landfilled only if their utilisation is either technically or economically impossible.

The European Union has set an objective to develop itself as a recycling society, where waste generation is avoided, and wastes generated are utilised as a resource. The latest waste directive from 2008 [7] contains an article for re-use and recycling of materials. Among other things, it requires that the member countries have to proceed with necessary actions to recycle materials and products. To fulfill the normative requirements, the industries and R&D are in charge to develop products that can be easily recycled. In the wood product sector, the waste hierarchy is largely underdeveloped, so far. A lot of wood products that could be utilised in secondary product life cycle are burned for energy or are down cycled that they lose material properties of solid wood. On the one hand, this reduces the competitiveness of wood as a construction material not only from the ecological, but also from the business point of view. On the other hand, it offers an obvious opportunity for innovative companies to create new business models, processes and products.

To reach the requirements for recycling, the knowledge about the sources, the quantity and quality of reclaimed wood is necessary.

There are various studies in EU market, which quantify the usage of wood in market shares [1],[2],[3].Up to now no exact evaluation is confirmed on how much recycled wood exists in our building stock and how high the potential of reuse or recycling is from this material source. There is already a small amount from recovered wood used in the production of particle boards or wood fibre products but it is a small share. Explicit calculations on quantities of recovered wooden material in building sector have not yet been done.

Beside precise evaluation about volumes of wooden material for reuse purpose, reuse and recycling faces other obstacles. Wooden material can only be reused if it is not contaminated with harmful substances. Timber has been treated with poisonous chemicals since the beginning of the 20th century, to reduce the risk of mould or to impregnate it against insects. This fact decreases the possibility of reuse and even recycling of reclaimed wood nowadays. For reuse purposes the contaminated wood has to be identified and its amount has to be quantified. Additionally the type of chemical treatment has to be analysed for bio hazardous substances and human-hazard toxicity of treated timber construction. These quantities have to be sorted out and treated according to the rules for hazardous wastes, in Germany the recovered wood regulation [8].

According to German law the term used wood (Altholz) means used wood from production and end user, as far as it is covered by the German life-cycle Resource Management Act.

The used wood is divided up in four categories, in order to decide which wooden material is usable for which waste scenario.

a) *Waste wood category A I:*

Waste wood in its natural state or only mechanically worked that during use was at most insignificantly contaminated with substances harmful to wood

b) *Waste wood category A II:*
Bonded, painted, coated, lacquered or otherwise treated waste wood with no halogenated organic compounds in the coating and no wood preservatives,
c) *Waste wood category A III:*
Waste wood with halogenated organic compounds in the coating with no wood preservatives,
d) *Waste wood category A IV:*
Waste wood treated with wood preservatives, such as railway sleepers, telephone masts, hop poles, vine poles as well as other waste wood which, due to its contamination, cannot be assigned to waste wood categories A I, A II or A III, with the exception of waste wood containing PCBs [9].

Reuse of construction parts is problematic because of a wide spread of unplanned demolition. For optimal reuse the available construction parts have to be identified and classified at least for different end-of-life scenarios. Construction wood and engineered wood products can be dismantled easier than most other parts, because they are used in dedicated layers, they are often used in modular assemblies and they are light-weight. The wooden parts are mostly serialized and the dimensions of certain parts are identical. All these themes make wood suitable for reuse. After the planned dismantling process of removable parts, the rough demolition of monolithic portions can take place. Such fractions may contain smaller amounts of wooden bits and pieces which are reserved for recycling or thermal use.

3. Related outcomes of ECO2-project: wood in carbon-efficient construction

The European woodwisdom research project ECO2 – wood in carbon efficient construction focused on creating holistic understanding of carbon efficiency in the full life-cycle of wooden building and defining technical potential and obstacles for the use of wood in carbon efficient construction. Aim is a clear minimisation of carbon emissions during production, construction and in the full life-cycle. Different case studies on life cycle of wooden products and buildings were examined and energy and carbon balance examined.

3.1 General framework on lifecycle assessment in buildings

According to the standard EN 15978: *sustainability of construction works – Assessment of environmental performance of buildings – Calculation method* the lifecycle of a building is divided up in different modules from A to D. Figure 2 shows the division in phases and the input of residues in lifecycle. In that context all scenarios for recycling and in general end of life of a product are integrated in module C. Modules include deconstruction / demolition (C1), transport to the product's waste processing (C2), waste processing for reuse, recovery or recycling, recovery and/or disposal (C3), disposal (C4).
To show possible benefits and loads of materials beyond the product system boundary, an additional module D is introduced. This means that in module D the recycling potential, the persistence of mineral building products, avoided impacts of thermal energy recovery, embedded renewable energy or carbon stored in the product can be shown. Up to now end-of-life scenarios for wooden products nearly only consist in incineration and energy recovery.

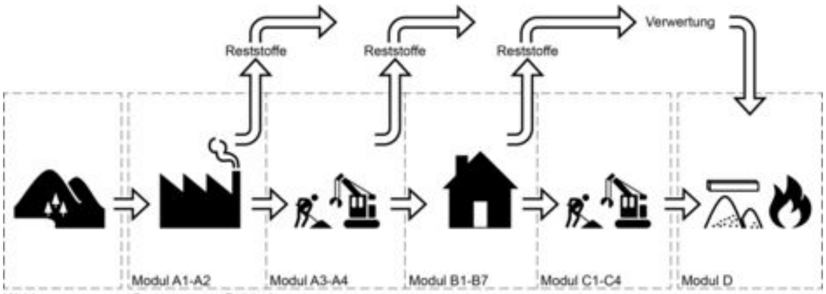

Fig. 2: residues from wood production in different phases of lifecycle

Therefore the treatment of carbon in life cycle analysis is a crucial factor which is not handled equally in LCA calculations up to now. System boundaries for calculation of building LCA were defined. The red line in figure 3 shows a simple system boundary for practical implementation of carbon footprint analysis. An assessment of this system provides information about the impacts of processes to produce, consume and disposed of a unit of a product / building. This approach aims at describing environmental properties of a building in its life cycle. But it does not include induced effects from changes in outputs such as shifts in production and emissions from other products that are displaced by the product being assessed. [11]

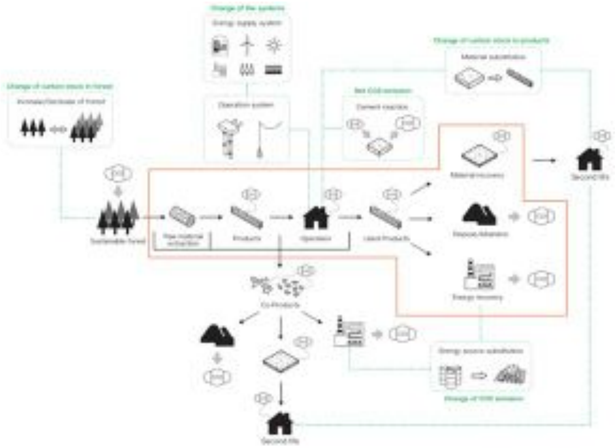

Fig. 3: Holistic picture of carbon footprint related to a wooden building system and simplified system boundary for the system building including only direct environmental effects.

Growing trees in the forest embed carbon in the material. Wood from forest is counted with negative greenhouse gas emissions in module A due to the carbon stored in the product. The biogenic carbon emissions directly attributed to a woodbased product result either from the use of biomass energy in production phase (module A) or from combustion of the product after end-of-life (module C). These emissions are equal to the amout of carbon sequestered in the growing tree which provides the biomass for the wood or the energy used. Prerequisite for that is always that sustainable forestry is applied. Several LCA calculations therefore regard wood as GHG neutral and don´t calculate them at all. This is only the case if calculations include the whole life cycle from production to End-of-life, if the wood is not leaving the forest system and if these forest are not being harvested. LCA calculations done according to the standards of EN15804 and EN15978 do not give instructions for the handling of wood and sequestration of carbon. But according to these standards the carbon and primary energy have to be accounted separately in the different modules. This requires that carbon balance is shown divided up in the modules. Hence wooden materials become a negative value in module A1 and a positive value in C4. Energy gains and the carbon stored in the product (if it is reused or recycled) have to be shown in module D. The overall carbon balance is still zero, but it can be divided among the different modules. By recycling or reusing wooden material at end-of-life for asecond life-cycle, carbon storage gets prolonged.

3.2 Characteristics of wood in end-of-life of LCA

While buildings are seen as a whole in the use phase, for end-of-life it comes down to the specific construction and the materials they are made of. Building components can be decomposed into different layers to get a deeper understanding of their impact at end of life, compare Figure 2. The layers of the building have different exposures, durability and therefore a different life span. The disassembly allows the identification of required service life of building parts and has to be considered in maintenance, inspection, end-of-life scenarios. In modern (timber) buildings different layers are also common to fulfill a wide variety of technical requirements.
Figure 4 shows the different layers of a façade divided into its technical and functional layers. The

primary construction needs to outlast the whole life span, wooden primary construction has high mass and can store a high amount of carbon over this period. The other layers e.g. cladding will be replaced many times and therefore are relevant in terms of recycling potential and burdens / benefits at EoL stage. This can be used as design methodology for the improvement of environmental performance. Through the interdependency of use- and EoL-scenarios, the different layers can seperatly be optimized more easily and then be designed for reuse. The jointing between layers and the frequency of renewal are additional criteria for the end-of-life phase apart from the material impact. [11]

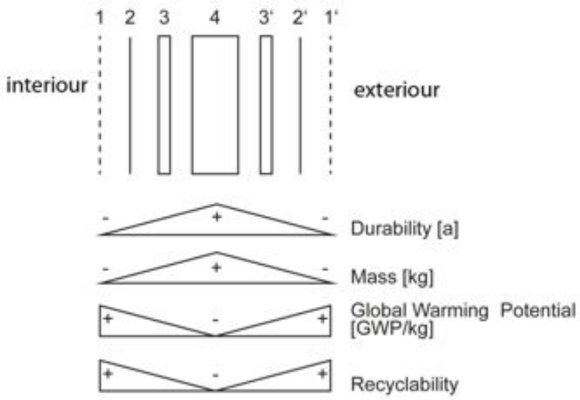

Fig. 4: Sequence of technical and functional layers and weighted influence on EoL impact below. 1) paint 2) cladding 3) functional layer 4) load bearing structure. [10]

In general the options for end-of life module for wooden products are:

<u>Energy recovery:</u>

Energy recovery means that the material gets burned in incineration plants. Then the embedded primary energy stored in wooden products gets released and a heating value is generated.

Incineration with energy recovery is useful for various materials like:

- Wood contaminated with paint / lacquer
- Wood contaminated with toxic substances (like PCP, impregnation)
- Small wooden parts which are bound together with glue
- Other materials that cannot easily be separated.

According to the German used wood categories described previously, energetic recovery is feasible for categories A III to A IV and in parts A II. Module D would contain avoided impact of electricity production and thermal energy recovery and emissions associated with wood combustion.

<u>Material recycling:</u>

"Recycling" means any recovery operation by which waste materials are reprocessed into products, materials or substances; whether it is for its original or new purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations" [7].

Material recycling can only be applied for wooden materials in category A I, and there must be a strict selection process to ensure that no contaminated material gets reused. Up to now the selected material for recycling gets used for soft board production only. Module D would contain avoided impacts of forestry, harvesting, wood chips preparation and drying.

<u>Reuse:</u>

"Re-use" means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived." [7]

Reutilization: For example, massive timber construction is deconstructed and reused for the same purpose.

Subsequent use: For example, solid timber construction is deconstructed and then cut into parts to be used as beams for roofing. The compounds are down cycled but the material still has some of

its properties.
This reuse is only useful for wide-span structures and laminated beams that have no material faults. For reuse, it is important that no preventive wood protection is applied to constructions; while for easy deconstruction it is beneficial to screw joints rather than nailing and clipping. This means that recommendations need to be made for design for reuse / recycling [11].

4. Case study on an existing wooden building for calculation of quantities

Aim of this study was a realistic assessment of the material fractions to overcome rough estimations and theoretical scenarios for end of life. Exemplary investigations and calculations are done on an existing cottage in the Alps (Höllentalangerhütte), which is located in a sensitive natural environment. Focus of the study is the primary loadbearing construction, the related claddings, surfaces of interior and exterior and the quality of the parts.
For realistic estimation of material content the methods of building survey, classification of components, parts, materials and documentation for reuse, recycling and disposal of existing constructions were presented in [12]. Results are summarised here.
Basis for the examinations are an overall inventory analysis and documentation of existing construction with classification in qualities and quantities. Used methods were: research with existing planning material, survey on site and examination of material samples for hazardous substances. The work was divided in two parts:
The first part was of theoretical nature and based on a research in the archives for information about the history of the cottage, the development stages over the lifecycle with repairs, refurbishments and extensions. First calculations are done according to existing drawings to get knowledge about quantities and material usage.
In a second part a survey on site checked material dimensions for quantity surveying and also results in drawings of construction details with focus on materials. Damages of construction and possible use of harmful substances were besides documented on site. Material samples were taken to analyse them on harmful substances and wood moisture content was checked as well.

4.1 Case study of a cottage dedicated to demolition

The Höllentangerhütte is located in the northern Alps close to Garmisch-Partenkirchen. It is situated at a height of 1387m above sea level and can only be reached through a small and steep foot path. The cottage was built and completed in for stages and consists of a wooden log house, two-storey timber building with a post and beam construction on a stone masonry cellar and an additional stone building with masonry walls from light-weight concrete blocks. The first part was built at the end of the 19th century, the follow-up building phases were in the beginning and middle of the 20th century. The overall gross external volume is 1650 m³, the net floor area is 511 m².

The amount of wood contained in a historic cottage in the Alps, dedicated to demolition, was evaluated. It is an example for construction with a long life cycle with numerous repair intervals, changes, building extensions, and a conglomerate of different materials.
Thereby reusing and recycling is not possible without a careful separation of the materials, which are non-toxic and toxic. Via pyrolysis and use of spectroscopy harmful substances like polycyclic aromatic hydrocarbon (PAK) and Pentachlorphenol (PCP) in coatings were detected. Result of the analysis showed, that the main part of the timber construction could be reused as further components. Only parts of the façade cladding and materials included in the construction phase of the 1960s contained hazardous substances. Most material from the original cottage is free of harmful substances and is also in good and dry condition. 6.7% of wooden material contains harmful substances, mainly the cladding which is exposed to painting in the last decades of the 20th century.

4.2 Results

Although the cottage Höllentalangerhütte is an example for buildings mainly built from wooden material results show the following. Analysis of material fractions in mass and volume show a high percentage of massive material in the cottage. The share of wooden material reaches a share of 38% in volume with very simple wooden constructions and a mass of 14 per cent. The main mass is 63% concrete / stone. Complete analysis of construction is shown in figure 5.

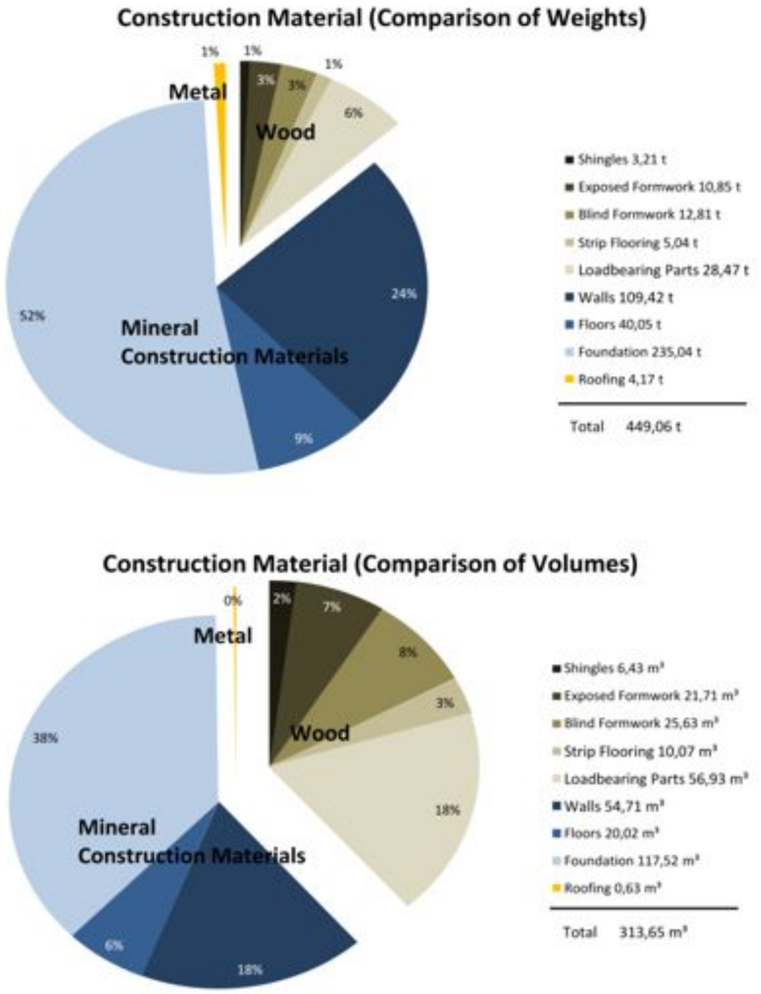

Fig. 5: Construction material – different fractions. Comparison of volume and mass [12]

To compare results to calculations done in chapter 5 a combined value of m³ wood per m² gross floor area is introduced. It is 5,1 m²/m³ or as a reciprocal value 0,20 m³ wood per m² gross floor area. This value shows the amount of used wood in comparison to the m² of gross floor area.

5. Analysis of wide-span timber structures

The problems of the reuse of contaminated wood shift the focus on younger buildings without chemical treatment of the timber construction. Especially the high quality engineered wood products like glulam, solid wood panels or CLT are in focus during data mining. The collection of data is limited to roof structures made of wood, as they are relatively easy to evaluate, compared to wooden buildings, empowering them to make a more meaningful statistic. The available beam dimensions and products of wooden roof structures are well suited for reuse. For evaluating 116 hall structures, as well as other large-scale structures, a wide range of use, size and age, are recorded in tabular form. A comprehensive evaluation but also a heterogeneous result is achieved with these data. The evaluation is adapted as a whole as well as on the individual vehicle types and assessed collectively in the summary statements.
The classification of the parameters starts with the desired result, the amount of used wood. To estimate the amount of used wood, span, beam depth, truss spacing and truss number as input variables are necessary in addition to the truss form and design. To describe the use of wood in a structure sufficiently accurate, it is necessary to explain it according to its shape-defining parameters. This is the consumption of wood in structures in relation to the footprint of the structures. This ratio m^2/m^3 allows a comparison of the trusses with each other. The relationship is suitable for a general assessment of the truss, since it contains all necessary parameters; with the counter, namely the footprint, which includes span, truss number and spacing, as well as the denominator, consumption of wood. The representation of wood consumption in relation to the floor space for each type of structure is calculated as an own indicator from the averages of the demand for wood and lined up floor spaces according to, compare figure 6. The nominal size of this factor increases the resource savings. With the inverse value one get the amount of exploitable secondary wood/recyclable material per square meter floor space.

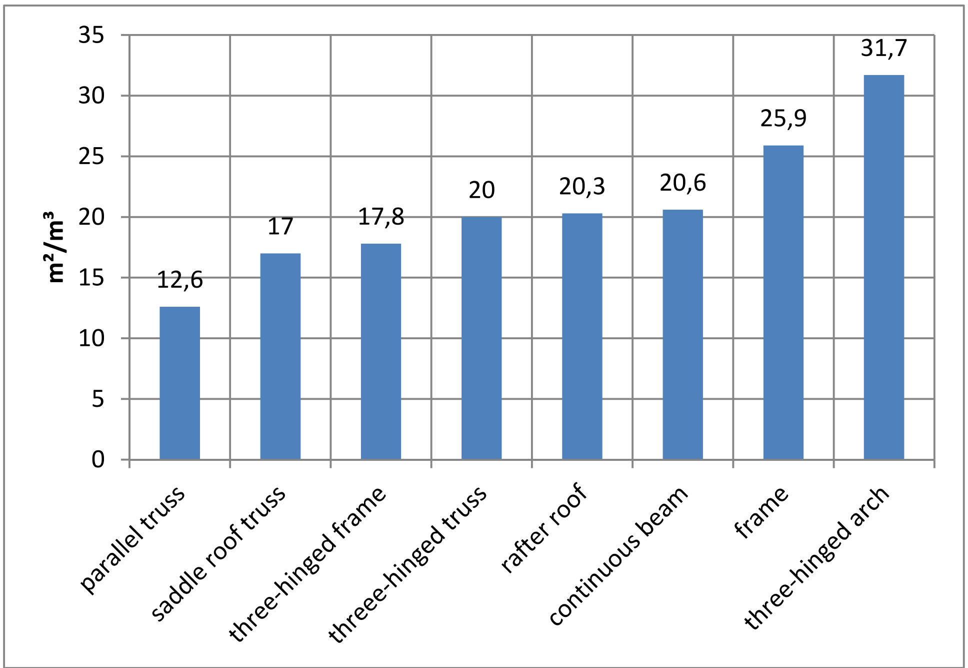

Fig. 6: Comparison of wide-span roof structures shows the covered floor space in relation to 1 m³ of used wood.

The evaluation could be completed with the statement, that the most used trusses have the lowest covered floor space in relation to 1m³ of used wood and therefore have the highest wood consumption. But there is far more to gain from the summary information. The vast distribution of values around the 20 m^2/m^3 mark shows that regardless of truss type evaluation evenly and properly worked. For the individual systems, no major differences have been expected. The values with the highest deviation of parallel trusses and three-hinged arch trusses are to be clarified separately. Other truss systems are better adapted to the load, such as the saddle roof truss, in which the distribution of the bending moment is optimized by an increased cross-section at mid-span. Parallel beams, in contrast, will have to bear higher bending stresses due to their constant cross-section; here, an increase in bending moment due to wider spans is simply countered by increasing the dimension of girders or higher trusses. This consequently increases the consumption of wood due to the increased volume over the entire beam length. The three-hinged arch also features a uniform cross-section, but since the load transfer is primarily realized through normal forces instead of bending moment, the structural system can be realized with a smaller cross-section.

6. Results

For future planning the reuse and recycling of existing buildings has to be integrated quite early in the planning process to be able to reuse the materials in the best way. Small scale drawings also show how components are built in and how jointing is done. This information is useful for dismantling.
With existing building documentation fictive mass calculation could be produced which then can be updated by partial surveys. In future architects contracts have to be enlarged to include also reuse of material in early planning stages.

The Höllentalangerhütte, as a case study, reveals that the more than 120 year old wooden construction still is in very good condition and could be reused in large parts. In parts where no maintenance and repairs were applied, like running water around broken rain gutter, the construction is mouldered and cannot be reused. Problems for recycling arise in the usage of harmful substances in paints. Here exact material testing is necessary. In general conclusion can be drawn that this Alpine cottage is an example for a simple building with a minimized construction which allows a high level of reuse. A reduced conglomerate of fractions makes separation easier and the additional economic effort could be limited.
The analysis of wide-span timber structures shows that there is an average amount of 0,05 m^3/m^2 of wood in these structures which equals about 21 kg/m^2 of softwood. Although there are losses due to the removal of construction joints and areas with dowels or nails, there is still a reasonable amount of quality engineered wood which can be reclaimed for a second use phase.
In the planning process for new timber structures design and construction has to integrate various possibilities to extend the life cycle of a product or material:
- Design for reuse
- Modularity of the structural system from components to the structural system
- Use screws instead of nails, clippings
- Extend the life span of the building and the durability of the products
- Easy dismantling of the buildings (connecting devices)
- Avoidance of composite materials
- Avoidance of toxic substances
- Use of waste wood fractions A I (only in parts A II)
- Maintenance, repair, renewal of surfaces (exterior and interior)
- Keep information about existing building through building passport (or sustainability certification)
- The prefabrication in the wood process is an advantage for durability and the end-of-life phase, as the construction has to be designed in modular elements. The replacement of single layers is possible through straight joints, so recycling becomes much easier.

Cascaded use of wood can affect the LCA positively, as carbon storage is prolonged. The material choice for wooden products will be influenced more positively, if the used wooden material is not burned immediately, but used as materials. Therefore, there is a need of a recycling proof and elimination concept for a future use of reclaimed wood of high quality.

7. Conclusion

The European Commission proposed to increase the efficiency in the production and the use of wood [5] and resource efficiency in general [13]. The overall goal must be to increase the long-term availability of renewable but at the same time limited resources for the wood cluster. The competition for raw materials between stakeholders in the wood cluster will be reduced and the wood utilization with immanent positive effects on climate protection will be optimized. An approach for higher resource efficiency is the implementation of a material flow management in the entire process of timber construction.

The latest waste Directive from 2008 [7] contains an article for re-use and recycling of materials. Among other things, it requires that the member countries have to proceed with necessary actions to recycle materials and products. To fulfill the normative requirements, the industries and R&D should develop products that can be easily recycled.

A better management of its renewable resources helps the wood sector to ensure a long-term availability of solid wood products at reasonable prices. This will allow preserving and also gaining market shares now and in the future.

For recycling of existing buildings exact calculation of actual mass and volume as well as building condition is necessary. Therefore drawings (as built) help to calculate overall quantities. They need to be checked on-site with survey. On-site survey focuses on quality of materials. Only on-site reliable information on the qualities of wood and usage of harmful substances can be gained. These analyses are important to choose material for recycling without introducing critical substances in the recycling process. For reuse the classification system has to be improved to the same level as the reclaimed wood classes regarding the contamination. This could be difficult, because the way of reuse is unclear and needs further development.

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