Holz – ein zirkulärer Baustoff

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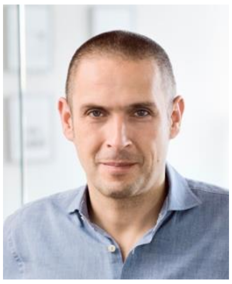

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1. Abstract

This paper presents a strategy how to maximise timber elements and materials from existing buildings for the reuse or the recycling for new construction. The EU funded project RE4 develops a new concept for disassembly to reuse or recycle timber elements from existing buildings for manifold application (structural and non-structural) and aims to bring waste wood back into the building cycle. Furthermore, an innovative design concept for fully reversible, prefabricated, multi-story residential buildings constructed from waste wood has been established to extend the buildings-life cycle through robust but flexible and adaptable design. Reversible connections, reusable elements and recyclable materials shall minimise future waste when buildings reach their end of life. A two-story prototype shall proof the concept and deliver figures for easy installation, dismantling and future reuse. The research aims to show how current practice can be overcome and design for disassembly can be achieved.

2. Introduction

The European building sector contributes annually to the overall waste generation with approx. 750 million tons of construction and demolition waste (CDW) [1]. Recovery rates (50%) are relatively low, especially as recovered materials are mainly used for low-grade applications or diverted to energetic recovery [2]. Vast amounts are still directed to landfill, as existing buildings were not designed for disassembly. During demolition, timber elements are often classified as Waste Wood Class A IV, to avoid time consuming investigations concerning wood preservatives. This in turn implies thermal recovery as only exploitation method. As a result, valuable, high quality timber is lost for the construction or refurbishment of buildings. The industry needs urgently innovative concepts for building disassembly but also for circular design to meet European goals regarding CDW waste reduction of 70% until 2020.

3. Concepts

3.1. Dismantling concept for existing buildings

A dedicated strategy for timber skeleton buildings has been developed as a desk study following the concept of selective dismantling that stipulates the dismantling process being executed in reverse sequence to its construction. The strategy has partly been assessed on different sites and will be described only very briefly with a focus on structural timber elements.

A comprehensive building survey (step 1), including information about the static system, superstructure, connections, location of timber elements, potential damages etc. and most importantly potential use of wood preservatives or other hazardous materials and potential occurrence of fungi and insect infestation present in the building, has to be undertaken, which should result into a comprehensive building inventory. In a pre-demolition audit (step 2), materials in their quantities and suitability for reuse or recycling are listed, taking into consideration economic constraints. On this basis a suitable deconstruction concept (step 3) will be defined, predicting salvaged quantities, material streams, required storage space, machinery and tools. Potential harmful substances must be appropriately removed (step 4) before the dismantling process starts (step 5 – 7). Where possible, timber elements (beams, columns etc.) should be removed in one piece, using suitable tools unfastening the respective connections or in case of inextricable bonds (e.g. nail-plates) cut into sections with a maximum length. Specifically, for façade elements, all functional layers can be kept, as it is intended to lift the element directly onto a vehicle for direct transport to a workshop to reduce onsite storage and to speed up the entire process. To minimise damages to dismantled elements suitable moisture protection shall be provided through foils etc. All stages of the strategy are attendant by a quality assurance, including the labelling of the dismantled elements to enable full traceability.

3.2. Material and design concept for timber elements

Due to a sustainable forestry management, introduced as an operational principal at the beginning of the 18th Century and reinforced by the European Commission in 2008 (Green Public Procurements), timber as a renewable resource exceeds current demands. However, growing numbers of timber constructions as well as increasing CO2 emissions related to waste generation, transport and production of construction materials generally imply a mindful handling with resources. The reuse and recycling of waste wood offers therefore significant potential to increase the positive impact of timber as a construction material even further. In addition, matured wood demonstrates a higher resistance regarding insect infestation, due to better growth conditions (fewer environmental pollution), longer growing periods and drying times and logging according to specific dates or moon phases (lower economical pressure).

If waste wood shall be reused or recycled for construction purposes it must be free of

- wood preservatives
- other pollutants resulting from previous uses that might have penetrated the wood
- wood-destroying fungi and insects
- any metal impurities that could damage machinery for reprocessing
- and demonstrate sufficiently strength, large cross-sections and lengths

Harmful substances

The Waste Wood Ordinance regulates the handling of salvaged timber and implies that the absence of harmful substances must be proved in order to allow its reuse. In the absence of any rapid on-site test, material samples from retrieved elements (Figure 1) have then been examined in a certified lab and instructions for removal of timber layers were given by the respective expert, in case of evidenced wood preservatives, which in turn permitted the utilization of salvaged sections instead of thermal recovery.

Pollutants from previous uses

In case harmful substances or pollutants were used or applied in a building identified for dismantling, suitable investigations must prove that timber identified for reuse or recycling is not affected. As such cases could be excluded for the salvaged waste wood within the RE4 project, no special investigations were carried out nor required.

Metal impurities

Metal fittings are one of the main barriers that prevent the reuse and recycling of waste wood as such impurities can considerably damage wood working machinery, if they remain undetected. All timber sections have therefore been examined by means of simple metal detectors to identify any kind of metal impurity, which in turn has been removed by means of hand tools (Figure 4).

Strength grading

CDW timber has to be strength graded according to harmonised standards [3], [4], [5] and national grading rules. In situ strength assessments such as resistance drilling, wave velocity or penetration tests, mostly used for the assessment of heritage structures, have been excluded as these procedures are not suitable for the assessment of large quantities, would not deliver results for the entire section or are not fully reliable. Instead, on-site inspections have been carried out by an expert to categorise the timber, measure available sections and identify potential extend of decay, defects, damages and existence of wood preservatives. Based on the outcome of this assessment timber sections have been sorted and separated on site for further reprocessing and strength grading. All impurities (paints, coatings or other non-wooden substances) were identified and removed to obtain clean raw material that was cut and planed into rectangular cross sections (Figure 2 - 3). As access to a drying chamber could not be established, timber was not technically dried and the average moisture level of 20% required for strength grading was not always achieved.

As a next step the actual strength grading process was carried out and the cleaned timber sections were assessed with regards to dimensions and location of cracks, branches and slope of grain (Figure 5) and classified according to DIN 4074-1:2012 [6] into the relevant sorting classes, which led in turn to the respective strength class according to EN 338:2016 [7].

Figure 1: Timber for recycling

Figure 2: Timber reprocessing

Figure 3: Waste wood lamellas

Figure 4: Metal detection

Figure 5: Strength grading: assessment of lamellas regarding dimension, location and orientation of branches, defects, decays and cracks.

Additional requirements for lamellas, designated for glued laminated timber, regulated in superior standard were applied during production [5]. Lamellas were then being used for the production of timber beams and columns as well as studs for non-load bearing façade elements.

Load bearing timber beams and columns

The general design for structural timber elements (beams and columns) complies with EN 14080:2013 [5] and follows the principal of glulam timber, where single lamellas are joined, with a deviation to the connection of the single sections.

The design concept pursues the following main ideas:

- maximisation and optimization of usable sections from waste wood (Figure 6)
- omission of industrial glue for connection of single lamellas to provide material purity
- use of timber elements (dowels, infills) for connection of lamellas to provide glue less elements

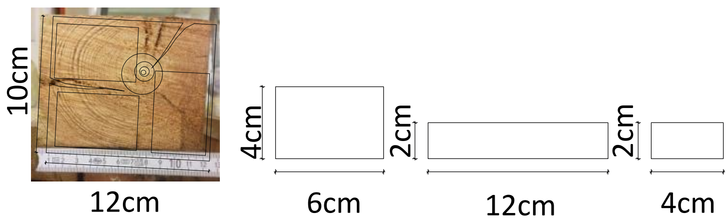

Figure 6: Possible division of salvaged timber sections

For the construction of the elements, core wood has been cut away from salvaged sections and obtained dimensions were assessed for suitability of different elements. For beams and columns initial trials have been undertaken and lamellas of 4/6/12 cm x 4 cm have been joined with natural glue in vertical and horizontal direction. To omit glue fully, structural elements have also been joined by means of timber connections, such as dowels and timber infills. Lamellas have been prepared, drilled and shaped in order to accommodate both timber dowels as well as timber infills. Timber dowels provide the general connection of the different lamellas, whereas the rectangular timber infills transmit occurring shearing forces (Figure 7 – 13).

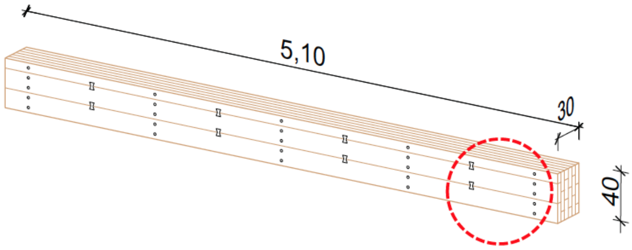

Figure 7: General design and dimensions for a glueless timber beam with dowels and infills

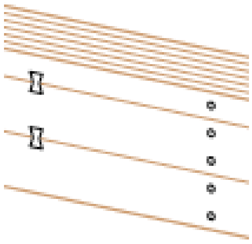

Figure 8: Timber dowels and infills

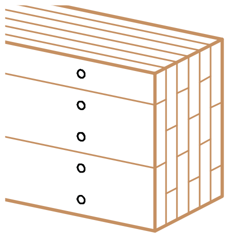

Figure 9: Layout of lamellas

Figure 10: Timber infill for shear force

Figure 11: Dowels for fixation of lamellas

Figure 12: Wedges for fixation of dowels

Figure 13: Small scale ceiling sample with dowels

3.3. Non-load bearing façade elements

The concept for non-load bearing façade elements pursues an amended strategy as such elements consist of various different components. Similar to beams and columns the general design aims to minimise material usage. Timber studs e.g. are reduced to a supporting framework, based on the dimensions of salvaged cross sections and possible division (Figure 14 - 15). Connections are also being investigated to construct carpenter connections, where possible. Furthermore, it is intended to use suitable scrap wood from the reprocessing for the manufacturing of wood fibre-based components in addition to demonstrating possibilities for the cascading use of timber within the element itself (Figure 16).

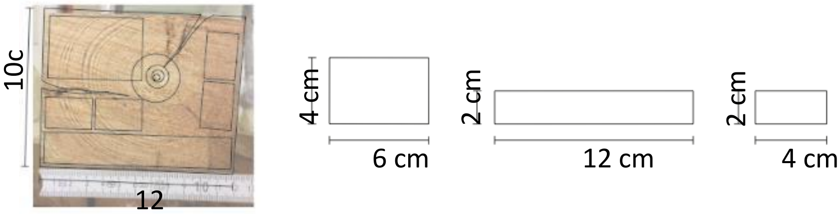

Figure 14: Salvaged cross section and possible division for material optimisation for timber façade elements

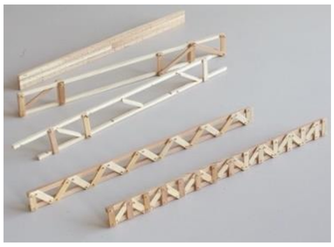

Figure 15: Model of studs with optimised material use

The design for the ventilated façade element proposes a self-supporting stud system that is covered either side with stiffening wood fibre boards. In certain load cases an OSB board might structurally be required to replace the wood fibre board to the inside. The panel is insulated with a blow in insulation, based on recycled timber flakes or fibres or wood fibre boards. The weatherboards are fixed with screws to a batten and counter batten system to enable future dismantling. An earthen plaster made from recycled aggregate is applied as a final finish to the interior, to provide a healthy and comfortable interior climate. All connections are either screwed or plugged as carpenter connections.

For the construction of the elements, salvaged timber sections are cut into the required dimensions of the single components e.g. weatherboards, studs etc. and off cuts are used for the production of wood fibres for wood fibre boards or insulation materials. Once the weather shell has reached its end of life, the boards can be dismantled, planned to remove decayed parts and further processed for the use of wood chips, suitable for the production of chip boards or wood fibre materials.

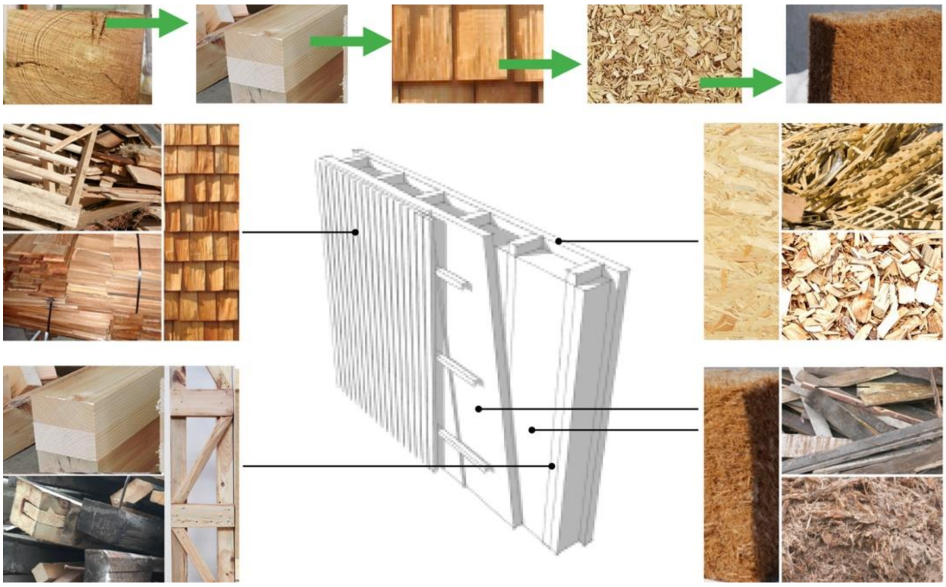

Figure 16: Cascading use of CDW timber for the production of non- load bearing façade elements

3.4. Design concept for reversible buildings

The design concept for a reversible building focuses on the lifespan of various building elements and enables meaningful divisions so that elements demonstrating a significantly shorter lifespan can relatively easy be maintained or exchanged. In addition, a high level of flexibility, decent ceiling heights and opportunities for adaptation shall generally increase the service life of a building. Although building elements are modular, they offer variation in size and shall be designed in such way that they can easily be dismantled and reused in future applications. In addition, they follow the concept of material purity or allow for easy dismantling so that the different components can be separated and reused or recycled if necessary. Additionally, the use of high-quality materials shall further increase the durability as well as the lifespan of the component and therefor also the building (Figure 17).

The design proposal suggests a timber skeleton support structure with reversible connections in combination with a stiffening core and a wooden non-load bearing façade system, all made out of CDW timber. The column system offers the highest level of flexibility when it comes to adaptation of floor layouts, whereas the non-load bearing system allows for a complete exchange of the elements, once they reached their end of life or in case of a use change of the building requires a different configuration.

Reversible connections, still under investigation, are planned for all connections. It is anticipated that they can either be realised as carpenter connections or through reversible, metal fasteners or connections.

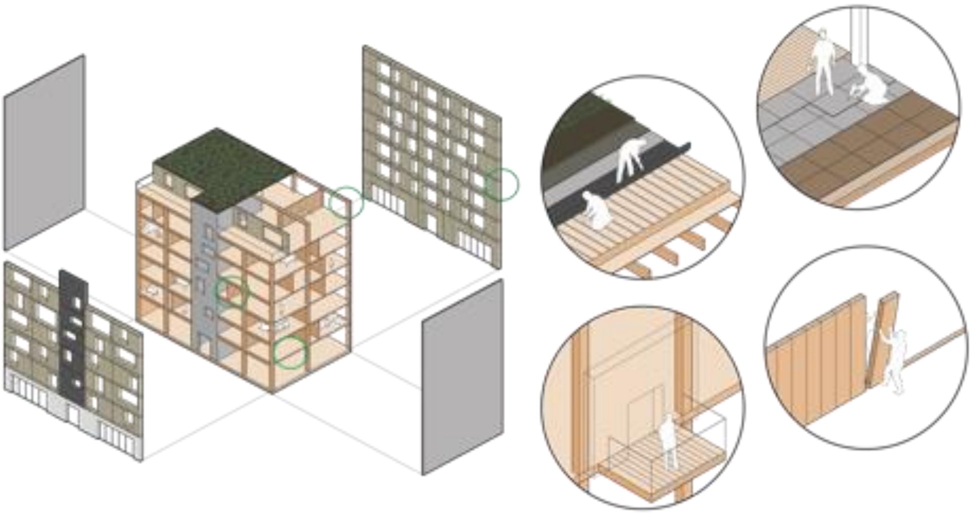

Figure 17: Design concept for a reversible timber skeleton building made from CDW

4. Results and Discussion

4.1. Dismantling concept for existing buildings

Although general principles for the dismantling process for timber skeleton buildings could be established, a detailed dismantling strategy uniformly applicable could not be developed, due to the large number of different timber structures and construction methods currently used in the building sector. However, it can be concluded that material efficient building deconstruction involves the planning, designing and implementation stage. According to Weimann an element-wise disassembly is best suited for wooden components in order to reuse as large proportions as possible [8].

Different site investigations and trials showed that selective dismantling offers the largest amount of timber available for future reuse or recycling. Irreversible connections e.g. nail plates or the use of different connection means (nails, screws with different bolt heads) slowed down the dismantling process significantly while reducing the amount of recovered material. Potential application of wood preservatives could be identified as the main barrier for timber reuse and recycling, as the verification process regarding the absence of pollutants was too time-consuming and too costly so that thermal recovery or landfill as a mean of disposal was chosen instead. Missing market opportunities for material reuse but also storage facilities for CDW in dense urban areas in combination with cheap fresh wood reduce the reuse and recycling rates further.

4.2. Material and design concept for timber elements

On-site inspections have proved to be an appropriate strategy to identify whether existing timber structures might be suitable for a direct reuse or recycling. Although, strength grading according to standard has been carried out on cleaned timber sections, initial on-site assessments delivered reliable results regarding the general structural capacity of the installed timber components and elements.

Furthermore, it could be established through firm lab testing that not constructions were treated with wood preservatives so that salvaged timber could be directly reused.

On-site investigations were also suitable for the assessment of timber regarding insect and fungi infestation. It could also be proved that by means of simple metal detectors that all metal impurities were identified.

The final strength class of the assessed timber achieved either C16 or C24, which is suitable for the development of structural timber elements.

In addition, initial trials for timber beams with natural glue delivered promising results. Experimental tests with regards to water resistance were successful. Elements based on glue less connections delivered a strong bonding. However final strength tests are still outstanding and will be conducted in the next 4 - 6 months.

4.3. Design concept for reversible buildings

The use of timber as a construction material offers generally much higher potential for reversible construction in comparison to concrete due to the light weight of the material itself but also do to the opportunity for dry connections. Furthermore, the concept of material purity is easier to achieve for structural elements as timber is able to take compressive, tensile and shear loads.

The cascading use of timber has been considered for all structural and non-structural timber elements and components, but has to be verified further through future application.

5. Conclusions and recommendations

5.1. Dismantling concept for existing buildings

Although selective dismantling offers the highest potential for material reuse and recycling, this method is rarely applied as deconstruction is mainly driven by economic factors (time, cost). Ecological benefits and necessities e.g. reduction of waste, CO2 emissions and extraction of primary materials, come mostly secondary. Higher cost for disposal, transport and raw materials could counteract that.

Furthermore, most of the building stock is not designed for deconstruction, which makes selective dismantling much more challenging. Design concepts for new constructions should therefore follow the concept of circular construction and allow for easy and speedy dismantling to increase the rate of building elements to be reused in future times.

5.2. Material and design concept for timber elements

Investigating aged timber, different factors have to be taken into account. The state of conservation, dismantling damages, and previous load condition can have an influence on the load capacity of the timber. Since the 1950's different research projects established that the influence of aging can be neglected if the state of conservation and other impurities are surveyed carefully [9].

The use of standardized cross sections can be helpful to avoid storage costs and increase the market acceptance for salvaged timber. Finger joints make the recycling of CDW timber very attractive as defects can be cut out and shorter pieces can be finger jointed into an endless lamella that can be cut into the required length.

Today, visual strength grading can be assisted by machines, which can lead to a better yield in higher strength classes. Traditionally grading machines work by bending the timber and assessing the stiffness. Today machine grading also includes technologies as flexural resonant frequency, x-ray measurements and ultrasonic wave speed.

To address the issue of wood preservatives, a kind of rapid on-site test would be desirable, as sampling and lab analysis is costly and time intensive. The Frauenhofer Institute developed a prototype for an on-site measurement device, which could be an opportunity to upgrade the classification of wood from demolition sites [10].

5.3. Design concept for reversible buildings

New material and construction concepts must be developed to allow the reuse and adaptation of buildings. In addition, today's planning process of new timber structures needs to take possible disassembly and reuse into account.

The growing digitalisation and increased use of Building Information Modelling (BIM) programs may in future revolutionize the deconstruction of timber buildings that are currently being planned and erected, e.g. information about the static system, detailed material properties, construction process but also completed conversions and extensions as well as repairs are already available during the planning of the dismantling.

Engaged component producers and suppliers in the aftermarket of products offering e.g. take-back systems for construction left-overs and possibly end-of use products, upgrades and repairs services etc. could support the reuse of building elements.

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